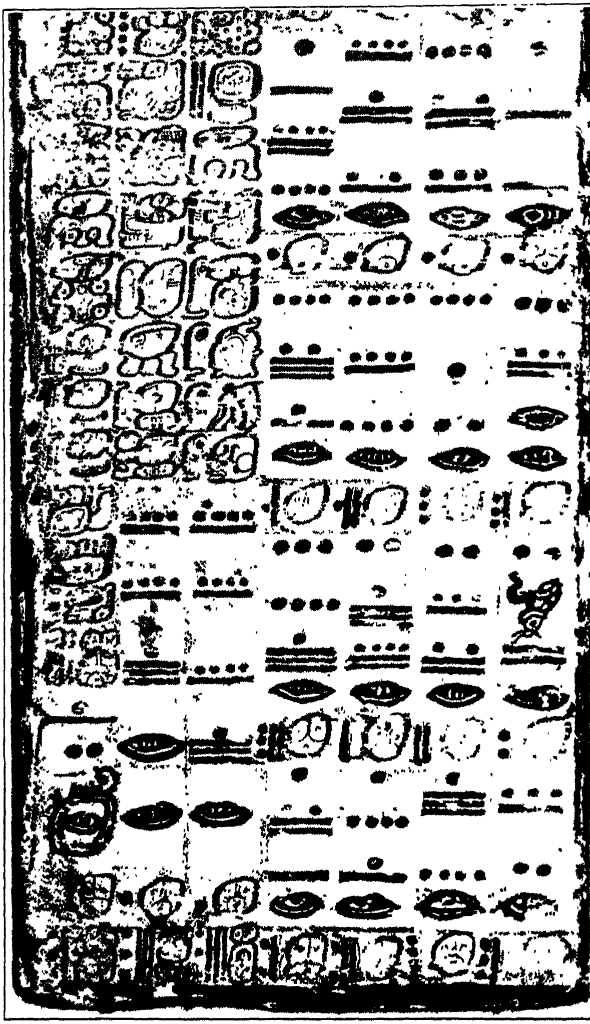

Fig. 1. From the Dresden Codex of the Maya, displaying numbers. The second column on the left, from above down, displays the numbers 9, 9, 16, 0, 0, which stand for $9 \times 144000 + 9 \times 7200 + 16 \times 360 + 0 + 0 = 1{,}366{,}560$. The numerals in the third column represent 1,364,360. The original appears in black and red. See Morley, p. 266. *An Introduction to the study of the Maya Hieroglyphs.*

The Early Mathematical Sciences in North and South America

FLORIAN CAJORI, Ph. D.
Professor of the History of Mathematics,
University of California

ILLUSTRATED

BOSTON
RICHARD G. BADGER, PUBLISHER
THE GORHAM PRESS

PRINTED IN THE UNITED STATES OF AMERICA

THE GORHAM PRESS, BOSTON, U. S. A.

INTRODUCTION

Small beginnings sometimes command our interest. The early years of American colonization were years of adjustment to new surroundings. One would expect the mathematical sciences to receive attention only in so far as they were necessary in such an adjustment. The navigator who brought the immigrant must understand navigation; there must be a determination of geographic positions. Indeed practical astronomy and surveying were necessary arts in the new world. But very early in American history the cultivation of the mathematical sciences passed beyond immediate necessities. There was evidence of a desire to cultivate science for its own sake. There was a craving for higher things. In true notes a poet sings of man:

> "He is not bound
> With earthward gaze to creep along the ground:
> Though his beginnings be but poor and low,
> Thank God, a man can grow.
> The fire upon his altars may burn dim,
> The torch he lighted may in darkness fail—
> And nothing to rekindle it avail—
> But, high above his dull horizon's rim
> Arcturus and the Pleids beckon him!"

The beginnings of the mathematical sciences are not confined to any one part of the western continent, nor to the people of any one nationality. Ancient American civilizations that have passed away disclose remarkable achievement. In more recent time, explorers missionaries, and immigrants from Spain, Portugal, Germany and Italy vied with the French and English in planting the first seeds in America for fruitage in science. There are some half dozen localities, mostly wide apart, which became the centers

of scientific activity—Mexico City, Mauritia (in Brazil), Boston, Philadelphia, New Haven, Williamsburg (Va.), Bogotá (Colombia), Paraguay. Most of these places became permanent scientific centers, a few unhappily proved to be ephemeral.

The development of science has not appealed to the multitude with the same force and fascination as do political and military events, which are usually the outcome of an upheaval of human passions. And yet, in the new world, as much as in the old, science has exerted great influence in human progress. Sometimes mathematicians have been the butt of genial persiflage, but there are serious minded readers who aim to go beyond mere foibles, and desire to contemplate the intellectual processes underlying the services which scientists rendered to society and to hear the stories of devotion and sacrifice accompanying their scientific achievements.

CONTENTS

ILLUSTRATIONS

THE EARLY MATHEMATICAL SCIENCES IN NORTH AND SOUTH AMERICA

THE EARLY MATHEMATICAL SCIENCES IN NORTH AND SOUTH AMERICA

CHAPTER I

MATHEMATICS

The Maya Symbol for Zero, the earliest in the World.

It is very fitting that we should begin our account of mathematics in America, by reference to the Maya number-system. (The earliest systematic use of a symbol for zero and the full development of a number-system on the principle of local value is due to the Maya of Central America and southern Mexico, whose wonderful civilization met with mysterious decay.) Their hieroglyphic writing has not yet been fully deciphered, except their number system and their wonderful calendar.[1] Maya ruins are now being zealously studied by archaeologists. The Maya symbol for zero goes back to about the beginning of the Christian era. The significance of this date appears from the fact that the earliest undoubtedly authentic occurrence of the symbol for zero in our Hindu—Arabic notation, in India, belongs to the ninth century, A. D. The Maya zero is centuries older than the Hindu zero. The Maya number system was not built on the scale of ten, but on the scale of twenty (except in one step); that is, 20 units (*kins*, or days) make one unit of the next higher order (*unials*, or 20 days), 18 *unials*

make one *tun* (or 360 days), 20 *tuns* make one *katun* (or 7200 days), 20 *katuns* make one *cycle* (or 144,000 days), 20 *cycles* make a *great cycle,* of 2,880,000 days. In the Maya codices one finds symbols for 1 to 19, expressed by bars and dots. Each dot stands for a unit, each bar for five units. For instance,

1 2 4 5 11 19

The zero is represented by a sign that looks roughly like a half closed eye (See Fig. 1). The numbers are written vertically, the lowest order being assigned the lowest position. The largest number found in the codices is 12,489,781.

For details relating to the complicated Maya calendar we refer to S. G. Morley. The Toltecs and Axtecs in Mexico had a number-system of less perfect development, and a calendar of 18 months and 20 days each. Five complementary days were added to make up the 365 days.

The Peruvian and North American Knot Records.

The use of knots in cords for recording numbers was practiced sometimes by the Chinese and some other ancient people, but the most remarkable development of knot records was among the Incas of Peru, from about the eleventh century, A. D. to the time of the Spanish conquest, in the sixteenth century. The quipu was a twisted woolen cord upon which other smaller cords of different colors were tied. The color, length and number of knots on them and the distance of one knot from another, all had their significance. Specimens of quipu have been found in graves. We produce from a work by L. Leland Locke[2] a photograph of the most highly developed quipu, (Fig. 2) also a line diagram of the two right-hand groups of strands (Fig. 3). In each group the top strand usually gives the sum of the numbers on the four pendent strands. Thus, in the last

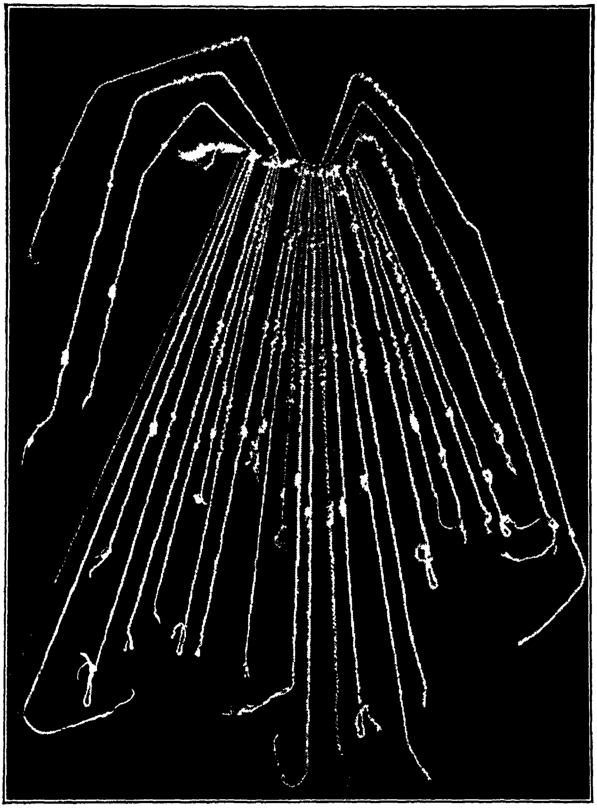

Fig. 2. A Quipu, from ancient Chancay in Peru, now kept in the American Museum of Natural History (Museum No. B8713,) in New York City.

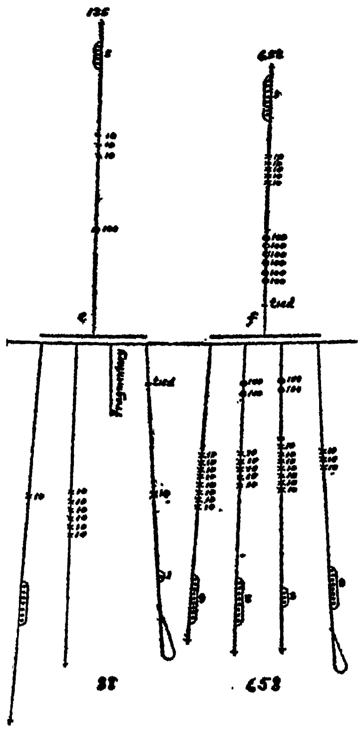

Fig. 3. Diagram of the two right-hand groups of strands in Fig. 2.

group, the four hanging strands indicate respectively the numbers 89, 258, 273, 38. Their sum is 658, as shown by the top string. The quipu were not adopted for computation; pebbles and grains of maize were used in computing.

Nordenskiöld[3] shows that in Peru 7 must have been a magic number, for, in some quipu, the sums of numbers on cords of the same color or the numbers emerging from certain other combinations, are multiples of 7 or yield groups of figures such as 277,777 etc. The quipu disclose also considerable astronomical knowledge on the part of the Peru Indians.

Among North American Indians[4] two types of less perfectly developed string records are used at the present time. One type found in the eastern part of the State of Washington is a long cord with knots and bearing beads, etc., to indicate the days. Another type, used in Arizona and California, is a cord bearing a number of knots to indicate the days before a ceremony, etc. This is sent with the messenger who carries the invitation. A knot is removed each day that elapses.

The Calderón and Cifrão in the Writing of Numbers.

A peculiarity in the writing of large numbers which is widely prevalent among Spanish Americans and Portuguese Americans is the use of a special symbol to designate "thousands." The Spanish symbol is called "calderón," the Portuguese, "cifrão." Both symbols are of European origin.

Most Europeans use commas in the grouping of numerals for easier reading, as in 734, 806. In place of this comma, Spanish Americans used a symbol resembling the capital letters U, or O open at the top. In a contract (See Fig. 4) written at Mexico City in 1649, the symbols "7U291e" and "VIIUCCXCI ps" each represents 7291 pesos. The U, or calderón, stands for "thousands." I. B. Richman has seen Spanish manuscripts ranging from 1587 to about 1700, and Mexican manuscripts from 1768 to 1855, all containing symbols for "thousands" resembling U and D, often crossed by one or two horizontal or vertical bars. The writer has observed that after 1600 this U is used both with Hindu-Abrabic and with Roman numerals; before 1600 he has seen it with Roman numerals only. As the Roman notation does not involve the principle of local value, the U played a somewhat larger rôle than merely to afford greater facility in the reading of numbers. Thus VIUCXV equals $6\times 1000+115$. This use is shown in MSS. from Peru of 1549 and 1543,[5] in MSS. from Spain of 1480[6] and 1429.[7]

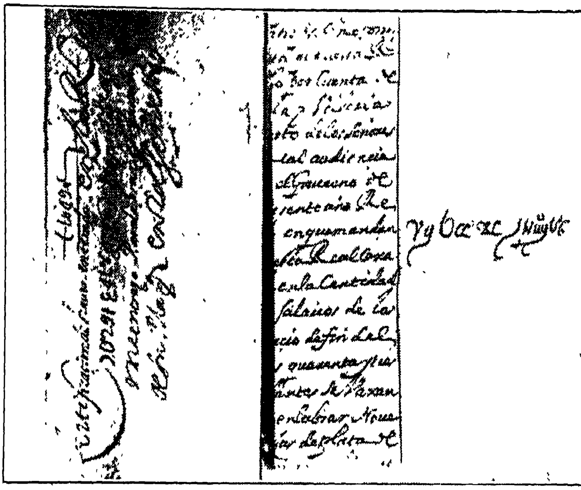

Fig. 4. From a contract, Mexico City, 1649. The right part shows the sum of 7291 pesos, 4 tomines, 6 granos, expressed in Roman numerals and the calderón. The left part, from the same contract, shows the same sum in Hindu-Arabic numerals and the calderón.

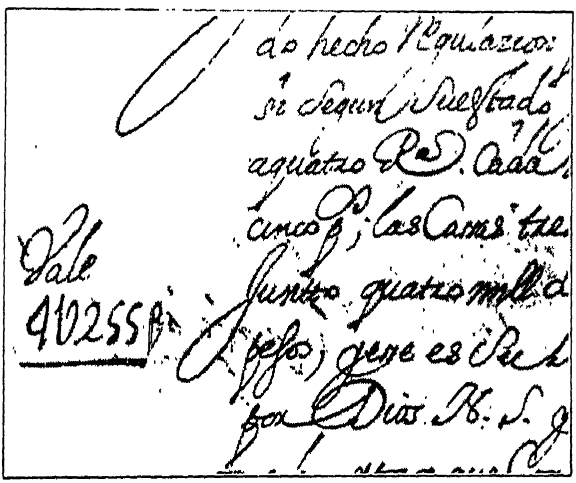

Fig. 5. Real estate sale in Mexico City, 1718. The sum written here is 4255 pesos.

We have seen the corresponding type symbol for 1000 in an account of coinage in the Real Casa de Moneda of Mexico in 1787, in eighteenth century books printed in Madrid[8] in the Gazetas de Mexico of 1784 (p. 1), and in modern reprints of seventeenth century documents.[9] In these publications the printed symbol resembles the Greek *sampi* ϡ for 900, but it has no known connection with it. In books printed in Madrid in 1760, 1655, and 1646, the symbol is a closer imitation of the written U, and is curiously made up of the two small printed letters "l, f," each turned half way around. The two inverted letters touch each other below, thus ʉ. Printed symbols representing a distorted U have been found also in some Spanish mathematical books of the seventeenth century, particularly in that of Texeda.[10]

The present writer has been able to follow the trail of this curious symbol U from Spain to north western Italy. In A. Cappelli's *Lexicon*[11] one finds a similar symbol for thousands used in Italy in the second half of the fifteenth century.

The Portuguese symbol cifrão looks somewhat like a modern dollar mark. Its function in writing numbers was identical with that of the calderón. Indeed, some written forms of the calderón need only be turned through a right angle to appear like the cifrão. Changes of that sort are not unknown. For instance, the Arabic numeral 5 appears upside down in some Spanish books and manuscripts, as late as the eighteenth and nineteenth centuries.

Evolution of the Dollar Mark.

There exist about a dozen different theories on the origin of the dollar mark, none of which have been carefully tested by appeal to the facts.

One of the most attractive of these theories carried the $ back to the "Pillars of Hercules" as they were impressed

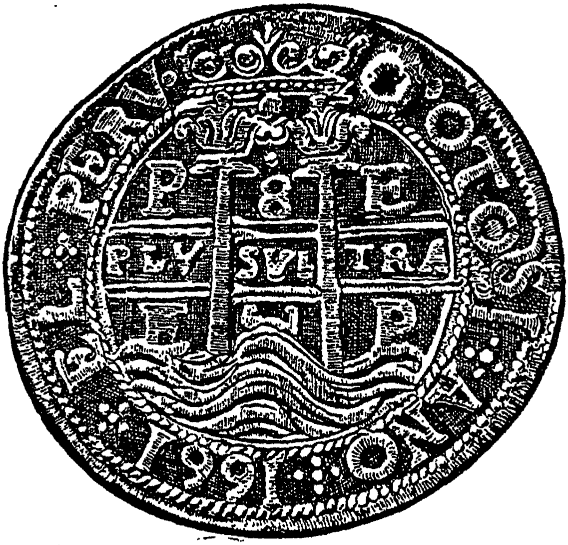

Fig. 6. "Pillar Dollar" of 1661, showing the "Pillars of Hercules" (From *Century Dictionary,* under "Pillar").

on the "pillar dollar," a Spanish silver coin widely used in the Spanish-American colonies of the seventeenth and eighteenth centuries. (See Fig. 6.)

A Spanish banner or a scroll around the pillars was claimed to be the origin of the dollar mark. It was supposed that the figure stamped on the coins was copied into commercial documents, but no manuscripts are known which show in writing the imitation of the pillars and scroll.

The only method of arriving at correct and certain conclusions on the origin of \$ lies in the painstaking examination of manuscripts and books. The present writer worked on this problem for several years, whenever opportunity presented itself for the study of manuscripts, and he accumulated a set of data which point unmistakably to the conclusion that our \$ or \$ is a modification of the Spanish-American abbreviation p^s for "pesos;" it is a florescent p^s, which

arose in attempts at rapid writing.[12] The earliest $ known to us occurs in a diary kept in New York in 1776. The first appearance in print was in Chauncey Lee's *American Accomptant,* Lansinburgh, N. Y., in 1797, but the form of the symbol in that book is somewhat different from that found earlier in manuscripts and from the form since used. After 1800 the $ began to appear in print and was also more frequently used in writing. It occurs a few times in Daniel Adams' *Scholar's Arithmetic,* 1807.

Magic Squares.

Magic squares, as a topic for mathematical recreation, is seldom encountered in early American publications. In a few arithmetics in the English language some simple magic squares are given for the amusement of children. Thus in Thomas Dilworth's *School-Master's Assistant,* an English text of 1744 or '45, which reached many American editions in Hartford, New York, Brooklyn, New London and Albany, there is in the "Short Collection of Pleasant and Diverting Questions" a problem demanding that the nine digits be arranged in a square in such a way that any three figures in a line may make just 15. This gives rise to the first of the following magic squares:

4	9	2
3	5	7
8	1	6

16	3	2	13
5	10	11	8
9	6	7	12
4	15	14	1

the origin of which goes back to early Chinese periods. Myth tells us that the enlightened Chinese emperor, Yu, saw on the calamitous Yellow River a divine tortoise whose back was decorated with the figure made up of the numbers from 1 to 9, indicated as knots in strings and arranged in form of a magic square. The earliest people, after the

Chinese, to amuse themselves with the magic squares were the Arabs, in the tenth century of our era. In Europe the first printed magic square appears on the wood-cut "Melancholia" of the Nüremberg painter, Albrecht Dürer, who gave the square of 16 cells shown on the preceding page. But in Italy, manuscripts indicate a knowledge of such squares about two centuries earlier.

It is of interest that Benjamin Franklin, who otherwise was not devoted to mathematical study, at one time was immensely interested in magic squares. In a letter to Peter Collinson he wrote: "I had amused myself in making these kinds of magic squares, and at length had acquired such a knack at it, that I could fill the cells of any magic square of reasonable size with a series of numbers as fast as I could write them, disposed in such a manner that the sum of every row, horizontal, vertical, or diagonal, should be equal; but not being satisfied with these, which I looked upon as common and easy things, I had imposed on myself more difficult tasks and succeeded in making other magic squares with a variety of properties, and much more curious."[13] He declared his square of 16X16 or 256 cells "to be the most magically magical of any magic square ever made by any magician."[14]

Mathematical Publications in America.

The mathematical printing press in America functioned earliest in Mexico. In 1556, sixty-four years before the landing of the Pilgrim Fathers, there was published there the *Sumario compendioso* of Juan Diez Freile,[15] which contains about 25 pages on arithmetic and algebra but is given mainly to the evaluation of silver and gold. Juan Belveder published a similar work in Lima, Peru, in 1597.[16] Pedro Paz,[17] a collector of tithes to the Metropolitan church of Mexico, published two arithmetical books, one the

Declaracion de los puntos, an explanation of the distribution of church taxes, Mexico, 1621, the other the *Arte menor . . . del Arithmetica,* Mexico, 1623, which appears to be not only the earliest regular treatise on arithmetic printed in America, but also the first one of American authorship. It has a sonnet opening thus:

> Entré, amigo Lector, conmigo en *Cuenta,*
> Queriendo darte *Cuenta* de esta Obra;
> Y por mi *Cuenta* hallé que aquello sobra,
> Que se pone de galas en la *Cuenta.*

The preface explains how the author receded from the original plan of writing an exhaustive work to that of a book containing only the simpler rules in integers and fractions adapted to the various forms of business, and excluding geometrical problems; it was intended for study without a master. The earliest text printed in the United States territory, in the English language and devoted entirely to to arithmetic, is James Hodder's *Arithmetick,* Boston, 1719; it first appeared in London in 1661. The first arithmetic printed in English and written by an American appeared anonymously, and is the *Arithmetick, Vulgar and Decimal,* by Isaac Greenwood, Boston, 1729. Greenwood was the first professor of mathematics and natural philosophy at Harvard College.

The only mathematical publication printed in America before 1800 and written by a woman, is the *American Instructor* (Philadelphia, 1747), written by Mrs. Slack of England under the pseudonym of "George Fischer." It was based on an English text, the *Instructor,* and enjoyed great popularity. The first American publication on *Logaritmos* was printed in Mexico about 1668. It came from the pen of Fray Diego Rodriguez of the University of Mexico, who left behind several unpublished manuscripts on mathematics, now kept in a convent in Mexico.[18]

It is not our aim to give, even approximately complete lists of mathematical text books published in America.[21] The above references are simply for orientation. Our aim is rather to display mathematical activity along the lines of independent research.

Among the earliest contributions to pure mathematics was a method of computing logarithms, by David Rittenhouse.[19] As very often happens in research, Rittenhouse was anticipated; the same method had been suggested somewhat earlier by Abel Bürja in Berlin.[20] Rittenhouse and John Winthrop in the eighteenth century enjoyed great reputation among their countrymen as mathematicians, though they had no mastery of the advanced fields of that science, and their best work was in observational astronomy. At the opening of the nineteenth century, in the field of mathematics, no one in the United States stood as high in popular esteem.

Perhaps the most noted was Jared Mansfield whose *Essays, Mathematical and Physical*[22] were published at New Haven without date, at first probably in 1801 and then again in 1802. This was the first volume of mathematical research issued in America. The contents of the book were, Of negative quantities in algebra, Goniometrical properties, Nautical astronomy, Of the longitude, Orbicular motion, Investigation of the Loci, Fluxionary Analysis, Theory of Gunnery, Theory of the Moon.

When the book was republished, in 1802, an Appendix was added: New Tables for computing the latitude and longitude at sea by means of double altitudes and lunar distances. The parts on practical applications of mathematics are perhaps more valuable than those dealing with theoretical mathematics.

Mansfield devotes an essay to the discussion of the negative in algebra, but his views were not in advance of those found in Nicholas Pike's *New and Complete System of Arithmetic* published in 1788, at Newburyport.

Says Mansfield:[23] "If ever the negative sign be prefixed to quantities which stand alone, and are unconnected with any other, the conclusion may safely be drawn, that they are either useless or absurd. Thus, if —a he added to —b, independently considered, there certainly can be no meaning to the sign —, and I consider the sum of these quantities to be nothing else than $a+b$." His exposition amounts to a denial of the existence of negative numbers. His treatment of imaginary or complex numbers and of vanishing fractions[24] was inferior to that found in the better comtemporaneous works in Europe. Mansfield is to be credited with a valid criticism of two papers written by James Winthrop and published in 1793 in the Memoirs of the American Academy of Arts and Sciences.[25] James Winthrop was librarian at Harvard. He claimed to have solved two time—honored problems first propounded by Greek mathematicians, one of them demanding the duplication of a given cube and the other the trisection of any given angle. We know now that the geometric construction of these problems is impossible with the limitations which the Greeks imposed, viz., that the only instruments used in making the constructions shall be a pair of compasses and an ungraduated or unmarked ruler. James Winthrop evidently did not have the mathematical ability and the knowledge of mathematics for which John Winthrop was justly famous. The marvel is not that James Winthrop made mistakes in the treatment of the duplication of a cube and trisection of an angle, but that his false solutions should have been accepted for publication in the Memoirs of the Academy. Not only does Jared Mansfield point out the error committed by James Winthrop in the duplication problem, but he gives expression to the belief that the solution of the problem is not possible. "By no means do I apprehend," says he, "that any proposition of Euclid, or of a right line and circle, are sufficient for this purpose."[26]

It should be noted that James Winthrop's error in his duplicating of the cube was pointed out also by George Baron, who wrote from "Hallowell in the District of Maine."[27] Baron had been mathematical master of an academy at Durham in England. Strictly rigorous proofs of the impossibility are algebraic in character and were first given in 1837 by the Frenchman P. L. Wantzel.[28]

In the trisection of an angle, James Winthrop laid himself open to attack, not because of any error in his demonstration, but because of his failure to observe the limitations which we are asked to observe in solving the problem. James Winthrop works out a trisecting curve, to which he gives no name, but which is a hyperbola. Perhaps the earliest to use the hyperbola in the trisection of angles was the Alexandrian Pappus.[29] We may add that James Winthrop frequently assisted in the taking of astronomical and meteorological observations and was more at home in this field than in theoretical mathematics.

In close relation to the pressing needs of American commercial life was the publication, in 1802, of Bowditch's *Practical Navigator*. Nathanial Bowditch (1773-1838) was a native of Salem, Mass., and came from a family of ship masters. When a boy he went to sea as a supercargo. He early displayed a love for mathematics. On the long sea-voyages during the years 1795 to 1804 he studied Lacroix's Calculus, which was the best text of that time on this subject. He learned French and German to enable him to read scientific books in those languages. During his years at sea he used John Hamilton Moore's *Practical Navigator*. He found many errors in Moore's work and published several revised editions of it under the author's name. The whole book at length underwent so many radical changes as to justify Bowditch to bring it out in his own name. The first American edition of Bowditch's *New American Practical Navigator* was printed in 1801 and was highly

recommended by the *East India Marine Society of Salem,* Mass., but was not published until 1802. The publisher, Mr. Edmund M. Blunt, took a printed copy of the work to England and sold it to the publishers of Hamilton Moore, on condition that the American edition should not be sold until June, 1802, so that an English edition could be placed on the market at the same time. The London edition was revised and newly arranged by Thomas Kirby and recommended as an improvement on Bowditch. A number of mistakes occuring in Kirby's edition were taken notice of by the author of a rival work in England, much to the annoyance of Bowditch who was not responsible for Kirby's errors.[30] Bowditch's Navigator came to be used widely and yielded him a considerable income. He continued to correct and improve it, as the demand arose for new impressions. Many editions of it appeared since the author's death.

After 1804 Bowditch gave up his sea-faring life. He became president of an insurance company in Salem, afterwards in Boston. His leisure time was given to science. He observed eclipses, meteors and comets, and computed orbits. But the great effort of his life was the translation, with extensive commentaries, of Laplace's great work, the *Mécanique Céleste.* The translation was begun in 1814 and, though completed about 1817, was not published till 1829-38. It appeared in four volumes. The cost of publication was defrayed from his private funds.

The courses in mathematics taught in American colleges at the close of the eighteenth century were still very meagre. But with the opening of the ninteenth century more substantial courses came to be introduced. Samuel Webber, for seventeen years professor of mathematics at Harvard College and later president of the College, published in 1801, in two volumes, his "Mathematics compiled from the best authors and intended to be a text-book of the course

of private lectures on these sciences in the University at Cambridge." These two volumes contained brief treatises on arithmetic, logarithms, algebra, geometry, plane trigonometry, mensuration of surfaces and solids, gauging, heights and distances, surveying, navigation, conic sections, dialing, spherical geometry and spherical trigonometry. Each subject was treated only very briefly. While such instruction well answered the purpose of general education, it was wholly inadequate for the training of specialists. There was no institution in America that could do for young men aspiring to eminence in the mathematical sciences what was done at the time by the Polytechnic School at Paris. An overflow of the French spirit reached America a little later, when John Farrar who in 1807 succeeded Webber in the chair of Mathematics and Natural Philosophy at Harvard, caught something of that spirit. In 1818 he published a translation of the *Algebra* of Lacroix and a year later the *Geometry* of Legendre. In 1820 appeared his translation of Lacroix's*Trigonometry* and in 1824 his *First Principles of the Differential and Integral Calculus* "taken chiefly from the mathematics of Bézout." These French works were at this time rather old, especially that of Bêzout which was written before the French Revolution. Nevertheless, they contributed to the raising of the mathematical instruction in this country to a somewhat higher level.

At Yale College Jeremiah Day became a professor of mathematics and natural philosophy in 1801. He set himself the task of preparing a series of mathematical texts intended to be somewhat more copious than were the volumes of Webber. In 1814 appeared his *Algebra,* and his *Mensuration of Surfaces and Solids,* in 1815 his *Plane Trigonometry* and in 1817 his *Navigation and Surveying.* These books were very elementary.

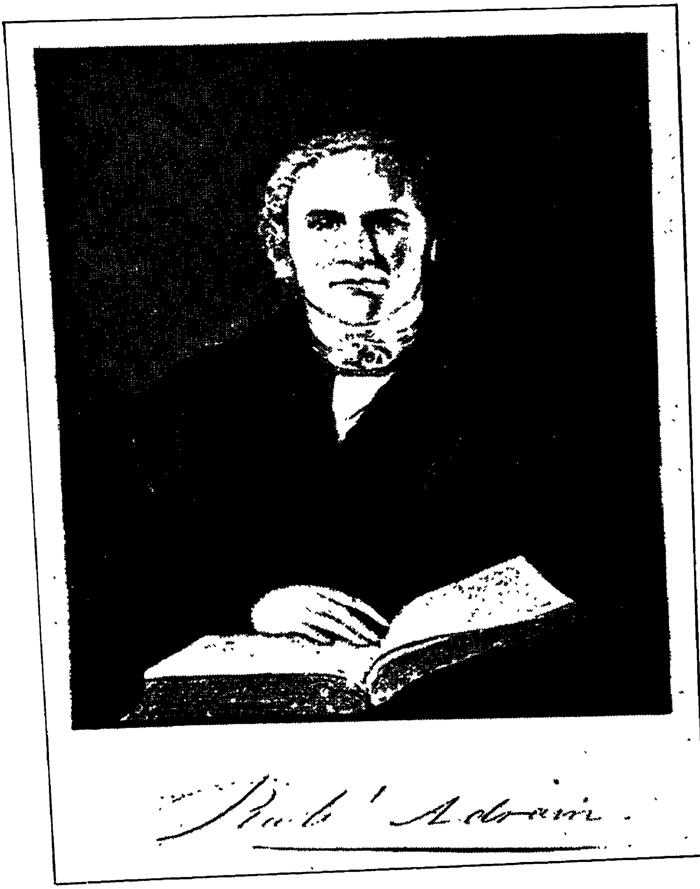

Fig. 7. Robert Adrain (1775-1843)

At the University of Pennsylvania Robert Patterson occupied the chair of mathematics and natural philosophy from 1779 to 1814. He was born in Ireland and at an early age showed fondness for mathematics. Navigation commanded much of his attention. "The regular publications of the Nautical Almanac, established by Dr. Maskelyne about the time (1768) when Patterson taught in Buckingham, Pa., turned the attention of the principal navigators in the American ports to the calculations of the longitude from lunar observations, in which they were eager to obtain instruction. Availing himself of this desire, he removed to Philadelphia, where he soon had for his scholars the most distinguished commanders who sailed from this port."[31]

Like all professors of mathematics in American colleges of that time, Patterson did not live in an atmosphere that encouraged advanced original research. Their energies were expended on teaching a wide range of topics. There existed in this country no libraries adequate for advanced study. There were no satisfactory means of bringing advanced researches to the attention of other scientific workers in the same field. Nevertheless, Patterson rendered valuable service to the country of his adoption. In 1805 his friend, President Jefferson, appointed him director of the United States Mint in Philadelphia. It was Patterson who recognized the native ability and unusual training of F. R. Hassler, who in 1805 arrived in the United States from Switzerland. It was he who brought Hassler to the notice of President Jefferson and urged Hassler's appointment as superintendent of the Coast Survey.

Outranking every American mathematician of his time was Robert Adrain, who was successively professor at Rutgers College, Columbia College and the University of Pennsylvania. Adrain was a native of Ireland and, having lost both his parents when he was fifteen, supported himself by teaching. He was wounded in the Irish rebellion of

1798. Soon after, he came to America. He contributed solutions to the *Mathematical Correspondent,* which was one of several early journals started at different times in the United States and devoted mainly to problem solving. For lack of financial support these journals had only an ephemeral existence. Adrain himself edited two of them at different periods, the *Analyst or Mathematical Companion,* and the *Mathematical Diary.*[32] He asked and answered questions involving the calculus of variations and elliptic integrals. He was a close student of Laplace's *Méchanique Céleste* and corrected some errors in that work. He was the first in America to pay attention to Diophantine analysis and obtained new theorems in that field. Robert Patterson had set, as a prize question, the practical problem in surveying, how to correct the measurement of a polygon whose successive sides are given in length and direction, but which, when plotted, does not close up. Adrain went into this subject deeply and was led to two demonstrations of the important exponential law of error, a law published a year later by Gauss and usually associated with his name.[33] Adrain's are the earliest proofs of this law; they were published in his *Analyst or Mathematical Companion* in 1808. They are defective, but none of the many proofs given since that time is accepted as perfect. In fact, as Professor J. J. Coolidge says, the law is "probably not strictly true and there is no such thing as a general law of accidental errors." Adrain proceeded to deduce from his law the process of least squares in the adjustment of observations, which had been published two years previously, without demonstration, by the French mathematician Legendre.[34] In contemplating his career, the question naturally arises, what greater achievements might not Adrain have reached under the stimulus, guidance and encouragement resulting from contact with his great European contemporaries.

1. See S. G. Morley, *An Introduction to the Study of the Maya Hieroglyphs,* Washington, 1915.
2. L. Leland Locke, *The Ancient Quipu or Peruvian Knot Record,* 1923.
3. Erland Nordenskiöld, *Comparative Ethnographical Studies,* No. 6, Göteborg, 1925.
4. See J. D. Leechman and M. R. Harrington, *String Records of the North-West, Indian Notes and Monographs,* 1921.
R. B. Dixon, "The Northern Maidu," *Bulletin Amer. Mus. Nat. Hist. XVII,* 1905, 228, 271.
P. L. Faye, "Notes on the Southern Maidu," *Univ. Calif. Publ. on Am. Arch. Ethn.,* XX, 1923, p. 44.
Stephen Powers, "Tribes of California," *Contributions to North American Ethnology,* III, 1877, p. 352.
F. H. Cushing, "Zuñi Breadstuff," *Indian Notes and Monographs,* VIII, 1820, p. 77.
5. *Cartas de Indias publicalas por primera vez el Ministerio de Fomento,* Madrid, 1877, p. 502, 543, facsimiles X and Y.
6. José Gonzalo de las Casas, *Anales de la Paleografia Española,* Madrid, 1857, laminas 87, 92, 109, 110, 113, 137.
7. Liciniano Saez, *Demostracion Historica del Verdadero valor de todas las monedas que corrian en Castilla durante el Reynado del Senor Don Enrique III,* Madrid, 1796, p. 477.
8. Liciniano Saez, op. cit.
9. Manuel Danvila in *Boletin de la Real Academia de la Historia,* tomo, XII, Madrid, 1888, p. 53.
10. Gaspard de Texeda, *Suma de Arithmetica Pratica,* Valladolid, 1546, folio iiii r., taken from D. E. Smith, *History of Mathematics,* Vol. 2, 1925, p. 88.
11. Adriano Cappelli, *Lexicon Abbreviaturarum,* Leipzig, 1901. p. L., facsimiles 436, 1. column, Nos. 5 and 6.
12. For details, see our article on "the Evolution of the Dollar Mark" in the *Popular Science Monthly,* Vol. 81 for January, 1912; and two articles, in *Science* N. S., Vol. 38, 1913, p. 848, and *School and Society,* Vol. 21, 1925, p. 625.
13. Benjamin Franklin, *Works,* Vol. 6, 1838, p. 101.
14. B. Franklin, *Literary Works,* Vol. 2, 1887, p. 159.
15. See a facsimile edition and translation into English, by David Eugene Smith, under the title *The Sumario Compendioso of Brother Juan Diez,* Boston, 1921.
16. J. T. Medina, *La imprenta en Lima,* Santiago de Chile, Vol. 1, 1904, p. 44. See also L. C. Karpinski, *The History of Arithmetic,* Chicago and New York, 1925, p. 78.
17. J. T. Medina, *La imprenta en México,* Vol. II, p. 109.
18. Mariano Beristain y Souza, *Biblioteca Hispano Americana Setentrional,* Vol. 3, 2. Ed., 1883, Art., "Rodriguez (Fr. Diego)."
19. *Transactions American Philosophical Society,* Philadelphia, Vol. 4, 1799, p. 69.
20. M. Cantor, *Vorlesungen über Geschichte der Mathematik,* Vol. 4, Leipzig, 1908, p. 442.
21. For details on the teaching of mathematics in America, see F. Cajori, *The Teaching and History of Mathematics in the United*

States, U. S. Bureau of Education, Washington, D. C., 1890; L. C. Karpinski, *History of Arithmetic,* Chicago, 1925; L. G. Simons, *Introduction of Algebra into American Schools in the Eighteenth Century,* Bureau of Education, Washington, D. C., 1924.

22. Mansfield, Jared, *Essays, Mathematical and Physical, containing new theories and illustrations of some very important and difficult subjects of sciences. Never before published....* New Haven. The latest date of an astronomical observation given in the book, is on page 134, "August 14th, 1800."

23. "Of Negative Quantities in Algebra" in his *Essays, Mathematical and Physical,* New Haven, 1801, p. 3.

24. Jared Mansfield "On Vanishing Fractions," Read April 17, 1816. *Transactions American Philosophical Society,* N. S., Vol. I, Philadelphia, 1818, p. 200-203.

25. *Memoirs of the American Academy of Arts and Sciences,* Vol. 2, Part I, Boston, 1793, p. 9-13, 14-17.

26. Jared Mansfield, "Observations on the Duplication of the Cube, and the Trisection of an Angle," Dated Oct. 2, 1809. *Memoirs of the Connecticut Academy of Arts and Sciences,* New Haven, Vol. I, 1810, pages 119-123.

27. *Memoirs of the American Academy of Arts and Sciences,* Vol. 2, Part II, Charlestown, 1804, p. 40.

28. P. L. Wantzel in *Liouville's Journal,* Vol. 2, 1837, p. 366-372. See also F. Cajori on "Pierre Laurent Wantzel" in *Bulletin Am. Math. Society* 2. S. Vol. 24, 1918, p. 339; Ambros Sturm, *Das Delische Problem,* Linz, 1895-1897.

29. Arthur Mitzscherling, *Das Problem der Kreisteilung,* Leipzig and Berlin, 1913, p. 88-91.

30. *Memoirs of the American Academy of Arts and Sciences,* Vol. II, 1846. Eulogy on Bowditch, note C.

31. *Trans. Am. Phil. Society,* Vol. II, N. S., Philadelphia, 1825, p. x.

32. A bibliography by D. S. Hart of early American mathematical periodicals is given in *The Analyst,* Vol. 2, Des Moines, Iowa, 1875, p. 131-138.

33. For details see J. J. Coolidge's critical and appreciative article on the work of Robert Adrain in the *American Mathematical Monthly,* Vol. 3, 1926, p. 61-76.

34. Recently Karl Pearson (*Biometrika,* Vol. 16, 1924, p. 402-404) and others have pointed out that the normal curve of errors was discovered as early as the eighteenth century. P. S. Laplace used it in articles on probability which appeared in 1778 in the *Histoire de l'académie des sciences* at Paris, and in 1774 in *Mémoires....presentes a l'académie,* T. VI, p. 6. Moreover, as early as Nov. 12, 1733, A. De Moivre had printed a small tract, *Approximatio ad summam terminorum binomii* $(a+b)^n$ *in seriem expansi* which contains essentially the normal curve.

CHAPTER II

PRACTICAL ASTRONOMY AND SURVEYING

Latitudes and Longitudes. Astronomical Observations.

The period of geographical discovery, with its long sea voyages, demanded the determination of latitude and longitude, to supplement data obtained from "dead reckoning." Owing to the crudity of the early instruments and the inaccuracies of astronomical tables, gross errors were made in early determinations. Columbus, when on his second voyage, observed at Haiti, in September 1494, an eclipse of the sun, and made a calculation which placed him 18° or about 1200 miles too far west. In Columbus' time Cuba was placed 7° or 8° too far north.[1]

Interest attaches to the question, what instruments Columbus used when he crossed the Atlantic. His original journal of the first voyage is lost, but an abstract exists. From it we learn that he used in addition to the magnetic compass, an astrolabe and a quadrant, instruments long known to navigators and astronomers.

The Magnetic Compass. The compass was an old instrument at the time of Columbus. Its invention has been ascribed to the Italian Flavio Gioja (1302), but it is certain that it enjoys a greater antiquity. At what time the magnetic compass was first used for land surveying is not exactly known, but in Europe it was probably about the early part of the sixteenth century. Columbus seems to have been the first to observe that the variation of the compass from the geographic north and south is different for different

localities. He found a place of no declination near the island of Corvo, one of the Azores. This observation, says Humboldt, marks a memorable era in nautical astronomy; Columbus made the ingenious remark that the magnetic variation might serve to determine the ship's position with respect to longitude. In the journal of his second voyage (April, 1496), he inferred his position from the observed declination. He had no means of knowing the difficulties encountered in the application of this method. We know now that lines of equal declination of the compass do not run regularly straight north and south, nor even approximately parallel with meridian lines; in some places they are more nearly parallel to lines of latitude.

That there are places of no magnetic declination seems to have been observed later, by Sebastian Cabot and he too suggested the use of the compass for finding longitude. We are told that Cabot still boasted on his death bed that there had been "divinely revealed to him an infallible method of finding the longitude."[2]

An impetus to the study of nautical astronomy and terrestrial magnetism was given by Pope Alexander VI when he issued a Bull on May 4, 1493, in which he designated a line from north to south, 100 leagues west of the Azores and Cape Verde Islands, and gave the Spaniards, the claim to all to the west, and to the Portuguese the claim to all to the east. Thereby he endeavored to dispose of the following complication: In 1454 Pope Nicholas V had given to the Portuguese the exclusive right of exploration and conquest on the road to the Indies, contemplating the only route, then known, by the coast of Africa to the south and east. Now, Columbus was supposed to have shown that the "Indies" could be reached also by sailing west. A dispute arose between Portugal and Spain as to their respective sphere of influence, and the Pope was appealed to. The Portuguese felt that Alexander VI (a Spaniard), in his

decision, was unfair to them. At a conference between the two powers, held in 1494, the line was shifted by common consent to 370 leagues west of Cape Verde Islands. This corresponded to about the 50th degree of longitude west of Greenwich. The exact location of the boundary was unknown. Portugal claimed eastern Brazil and the Spanish claimed the right to exclude all other peoples from places "beyond the line."

The Astrolabe goes back to the time of the Greek astronomer Hipparchus (2. Cent. B. C.). It is the earliest circular instrument employed in Greece for angular measurement. There are different types of astrolabes. That of Hipparchus was a kind of armillary sphere used in taking observations and also for illustrating the heavenly motions. Ptolemy (about 139 A. D.) seems to have used an astrolabe of the form of a large graduated ring like the one in Figs. 8 and 12. The instrument was developed by the Arabs.[3] It was used by Copernicus. One source of inaccuracy arose from the vibrations of the instrument when suspended by hand. Thomas Harriot wrote an unpublished description of the mariner's astrolabe.[4] The manuscript is in the British Museum and is entitled, "Some Remembrances of taking the altitude of the Sonne by the Astrolabe and Sea-ring." Probably he learned to use the instrument when crossing to Virginia.

The mariner's astrolabe shown in Fig. 8 was brought up, in 1903, in a sand pump when the harbor of Vera Cruz in Mexico was being dredged; it is now in the possession of R. T. Gunther of Oxford.[5]

It was not found convenient to carry about astrolabes of more than about six inches in diameter—a size too small for accurate angular measurements at sea.

The Quadrant. To secure greater accuracy the radius of the astrolabe was enlarged so as to make the divisions of an arc on a larger scale, and the resulting disadvantage

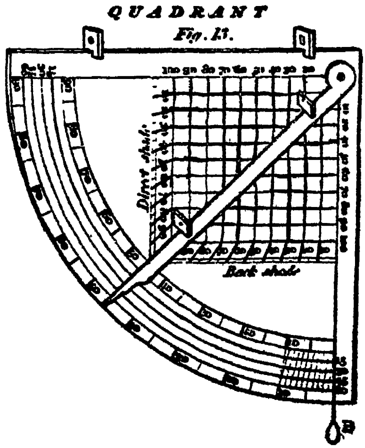

Fig. 9. A Quadrant from Rees' Cyclopaedia, 1819.

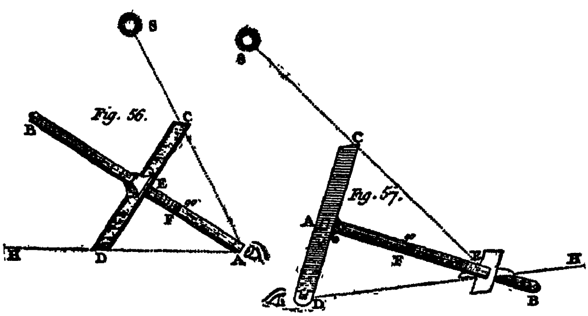

Fig. 10. A Cross-staff. From Bouguer, *Nouveau Traité de Navigation,* 1753.

of less portability was overcome by the construction of only one-fourth of the circle. Thus arose the instrument called the quadrant (Fig. 9). As angular altitudes never exceed 90°, the quadrant proved quite satisfactory. There is reason to believe that such quadrants were used as early as the time of Aristotle.[6]

Fig. 8. Mariner's Astrolabe from Vera Cruz. Observe the double graduation of the upper left hand quadrant; one progressing clock wise from 0° to 90°, and the other from 90° to 0°. The diametral arm that was turning on a pin at the center is lost.

The Cross-staff. It has been claimed that Columbus used also the cross-staff[7] (See Fig. 10). Others attack the validity of this claim,[8] arguing that Columbus does not mention this instrument and that there is no evidence that it was used in navigation as early as the time of the discovery of America. While the Portuguese seem to have used the cross-staff in navigation at that time, the weight of argument appears to favor the conclusion that Columbus did not use it.

The invention of the cross-staff has been traced to the French jew of the fourteenth century, Levi Ben Gerson,[9] who used it for astronomical (not nautical) purposes, as for instances, for measuring the angular distances of stars. His manuscript writings on this instrument were perused by the German astronomer Regiomontanus. The cross-staff was known to the Portuguese and, it seems, used by them in navigation before the close of the fifteenth century.

How Observations were Made. Except for short expeditions, the daily records of speed and direction ("dead-reckoning") of a ship were supplemented by astronomical observations. The latitude of a place was much easier to determine than the longitude. An easy method consisted in measuring the angular altitude of the North Star above the horizon. That altitude is about zero at the equator and about 90° at the North Pole, and is about equal to the latitude of the place of observation. An instrument such as the astrolabe (Fig. 8 and 12) could be used; it is simply a material circle divided into degrees with a rotating diametral arm for sighting purposes. It was held by hand in suspension from the ring and the sights of the moving arm were directed toward the star, whose altitude was then read off on the circle. In more refined measurements allowance is made for the fact that the North Star is not quite in the direction of the north celestial pole. The astrolabe was well adapted also for finding, roughly, the altitude of the sun at noon; it is shown in astronomy that from that

determination and the use of tables of the sun's declination, the latitude of the place of observation can be computed. But such determinations of the latitude were unreliable because of the inaccuracy of the early solar tables. The astrolabe could be used for measurements in bright sun light. If the sun was partially hidden behind a cloud, a direct observation on the sun could be made with a quadrant when the astrolabe would fail to yield results. The early quadrants were supplied with a plumb-line. There were two ways of using the instrument; one was to place an edge of the quadrant in a vertical position by the aid of the plumb-line and then point the movable radius toward the object whose angular altitude was sought; the other mode of procedure was to place the quadrant in any convenient position in a vertical plane, point the movable radius to the object and then read the position along the graduated arc of the quadrant taken by the radius and also by the plumb-line. The first process is shown in Fig. 9.

The cross-staff consisted of one or more cross pieces which slide along a long arm. From the readings on that arm and the length of the crosspiece, the altitude of a star can be found. The modes of use are shown in Fig. 10.

The difference in longitude between two places can be found by noting the exact times of an event visible simultaneously at both places—an eclipse, for instance; the difference in these times gives easily the difference in longitude. If in an eclipse of the moon, the shadow of the earth is seen at one place to touch the moon at 9 P. M., and in another place, at 10 P. M., the difference in longitude is one twenty-fourth of 360°, or 15°. This method goes back to the time of the Greek astronomer Hipparchus.

But eclipses of the sun and moon do not occur with sufficient frequency to satisfy all practical needs. Nor is the weather always propitious when eclipses do occur. If the two stations are far apart, one let us say at the Greenwich

Observatory or at Paris, and the other somewhere in America, the comparison of time observations would meet with long delay (unless ephemerides are available) on account of the slowness of intercommunication in olden times. It was Galileo who, using his new telescope, discovered that Jupiter had moons, and he made the happy suggestion that they might be used in the determination of longitudes. These moons revolve about Jupiter and are part of the time in the cone of shadow cast by Jupiter. The moment when, let us say, the first satellite plunges into the shadow, can be observed in two places whose difference in longitude it is desired to ascertain. As this satellite revolves about Jupiter once in less than two days, there are plenty opportunities for observation. Moreover, tables can be computed, giving the times of disappearance as seen in Paris or Greenwich, so that an observer in America possessing such a table, can compute the difference in longitude at once. If one observes the time of immersion of the satellite at Philadelphia, then finds in his table the Greenwich time of immersion, the difference of the two times gives the time-difference in longitude between Philadelphia and Greenwich, which can be easily translated into degrees. We shall find that in America the observation of the motions of Jupiter's satellites was very frequently resorted to, for the determination of longitudes.

Longitudes were obtained also from lunar observations and lunar tables. In any case accurate determination of latitude and longitude calls for accurate instruments. It is not surprising that early determinations were extremely crude. Even after the clock and telescope were available, gross errors arose. The mode of fixing the exact difference in the time of two distant places was greatly improved by the invention of high-grade chronometers. A chronometer set in England at Greenwich time, when transported to Boston, would be compared with the time at the Cambridge

(Massachusetts) Observatory. Thus the difference in time between the two observatories could be found. Eighteenth century chronometers were unreliable. Humboldt in 1803 found the difference in meridian between Mexico City and Acapulco by the aid of a chronometer, "worn out with five years travelling."[11] The invention of the electric telegraph afforded still more accurate determination of time differences between places telegraphically connected. The twentieth century brought the radio method of finding time differences. A radio message travels between Europe and America with the velocity of light; it affords degrees of accuracy in longitude determinations hardly dreamed of in the past. But the period of American science which we are studying antedates the invention not only of radio equipment, but also of the telegraph and the accurate compensating chronometer. The early periods in America preceded even the invention of the telescope and of clocks. Columbus is said to have measured time by the half-hour glass. The French geodesist, La Condamine,[10] in referring to a map of the region of Quito, engraved in 1707, by the German Jesuit missionary, Samuel Fritz, says: "Father Fritz, without clock and without telescope was not able to determine the longitude of any point. He had only a small half-circle of wood, three inches in diameter, for finding latitudes; finally he was ill when he descended the river to Para. One has only to read his manuscript journal, of which I have a copy, to see that many obstacles then and after his return to the mission did not permit him to make the observations necessary to make his map exact especially toward the lower part of the river."

Early Determinations of Positions in and near Mexico. We have already mentioned Columbus' observation of an eclipse of the sun at Haiti, in September 1494. There were, of course, many early determinations of positions of which

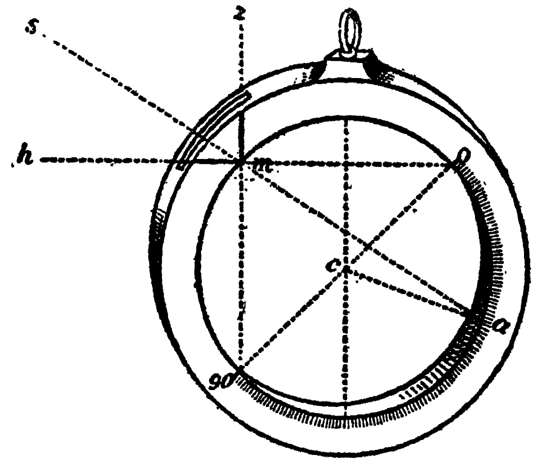

Fig. 11. Ring-dial or Sea-ring.

we have no record and which could not be enumerated here even were the data at hand. Thus in 1538, P. Nadal estimated the latitude of the junction of the Gila and the Colorado rivers, near the present town of Yuma, by measuring the meridian altitude of the sun, as 35° 0′. C. Delisle in his maps adopted the value of 34°. Father Kino in 1701, using an astronomical ring (anillo astronómico) gave it as 35° 30′, while the more accurate work of Father Juan Diaz in 1774, also using an astronomical ring, made it 32° 44′, and Pedro Font in 1775, 32° 47′.

The Ring-Dial. The astronomical ring, mentioned above, was used quite frequently on land and sea. It was a simplification of the astrolabe, and was also called the "ring-dial" or "sea-ring." A crude type is shown in Fig. 11. By noticing the spot upon which the solar ray *ma* fell, the angular altitude of the sun could be found in degrees. Sometimes the graduation on the inside of the ring was

adapted to the latitude of the place of observation, and served then for finding the time of day.

Another sixteenth century observer was Antonio de Mendoza, the first viceroy of New Spain (Mexico) who on October 6, 1541, wrote that by observing two lunar eclipses he had found the difference in time between Mexico City and Toledo in Spain to be 8 hours 2 minutes 34 seconds.[12] This yields for Mexico a longitude which is in excess of the true value by about 25° 33′. This longitude remained the accepted one during the sixteenth century. The eclipse of the moon of September 23, 1577, was observed in Mexico city, and also at Uraniburg by Tycho Brahe, and in other places by various astronomers. From the data thus obtained it followed that Mexico City was 104° 45′ west of Paris—a very accurate figure for that time—being less than 4° in excess of the true value.[13] Other determinations were wider from the mark, so that the figure adopted for maps of about 1600 were 7° in excess of the true value. An eclipse of the moon was observed at Huehuetoca, situated in the same meridian as Mexico, on December 20, 1619, by the Dutch engineer Enrico Martinez, but without the use of a telescope. That eclipse was carefully observed in Europe and yielded greater precision of many geographical locations. The various observational data were gone over by Fray Diego Rodriguez of the University of Mexico, the immediate predecessor of the famous Cárlos de Sigüenza; Rodriguez reached the conclusion that Mexico City was 101° 27′ 30″ west of Paris. This result was very satisfactory for that time, exceeding in accuracy the value reached by Alexander von Humboldt about a century and a half later and differing by only 12 seconds from the modern figure 101° 27′ 18″ due to Francisco Diaz Covarrúbias.[14] Rodriguez's determination of longitude did not become known in Europe, where geographers of the eighteenth century placed the longitude of

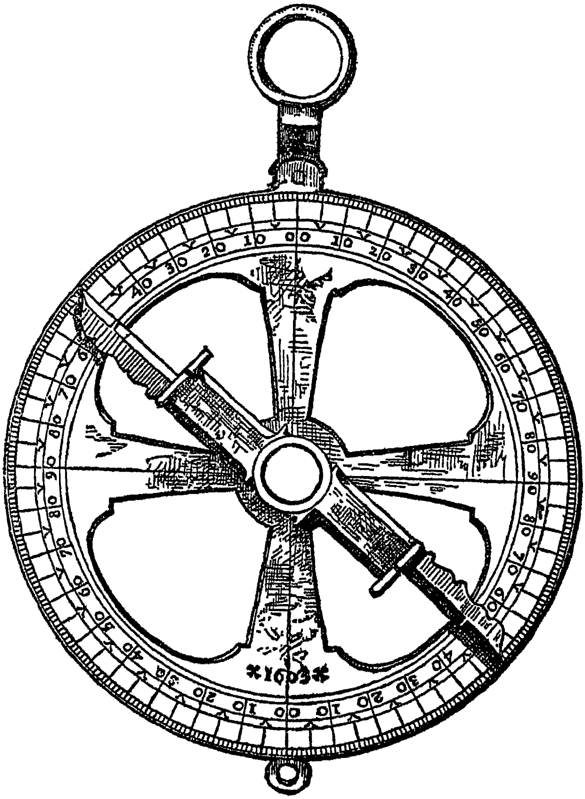

Fig. 12. The Astrolabe believed to have been lost by Champlain in Canada, on June 7, 1613. It was found in 1867.

Mexico as high as 106° and 107° 30′. Among the best eighteenth century determinations was that of Antonio Leon Gama. This modest but accomplished scientist was born and educated in Mexico. He studied the works of Newton, Wolf, Gravesande, Musschenbroek, the Bernoullis and Lacaille. He was connected with the school of mines in Mexico, calculated and observed eclipses of the sun, made determinations of longitudes and latitudes, and prepared a

dissertation on the aurora borealis. He was highly esteemed by Lalande, who secured the publication of Gama's scientific results in the *Connoissance des temps* in Paris.

Champlain's Astrolabe. Passing from Mexico to Canada, we encounter the French explorer Samuel de Champlain, who recorded astronomical observations on his travels. In 1867, an astrolabe (Fig. 12) was found on an old portage road at the Ottawa river which most probably belonged to Champlain and was lost by him in 1613.[15] On June 7, 1613 Champlain speaks of the difficulty of making a portage, which must have been at or near the place where the astrolabe was found. Before that date he records determinations of latitude regularly in degrees and minutes; after that date he gives only rough estimates in degrees. This fact was probably due to his loss of the astrolabe previously used in his measurements. The instrument found in 1867 was a circular brass ring 5⅝ inches in diameter, each quarter of which was divided into degrees, ranging from 0° to 90°. When held in suspension by a small ring attached to the edge, the 0° marks were at the top and bottom, and the 90° marks at the extremities of the horizontal diameter. When the instrument was freely suspended by the small ring and the index was pointed to a star, the angle which the index made with the vertical diameter gave the zenith distance of the star. This astrolabe weighs about three pounds and is kept as a precious relic of the time of French-American exploration.

The attention given to practical astronomy by early explorers is illustrated by a statement in a letter of the Jesuit Claude Chauchetière, written at Montreal, September 20, 1674: "I have others with beards on their chins, to whom I teach navigation, fortification, and other mathematical subjects. One of my pupils is pilot on the ship which sails to the north."[16]

Marcgrave's Observations in Brazil. Among the earliest astronomical observations in the new world that were carried on, not directly for practical purposes of navigation or cartography, but for the advancement of science, seem to have been taken in 1639 and 1640 by the Saxon astronomer and naturalist George Marcgrave, at the town of Mauritia on the island of Vaez, in the harbor of Recife (Pernambuco), in Brazil. His patron, Count Maurice of Nassau-Siegen, had built him an observatory of stone.[17] According to one writer, Count Maurice erected a palace with two towers, one of which was used as the observatory. Marcgrave was well trained for scientific work. He had spent eleven years at various German universities and had received a great longing to study the southern stars, and natural history in the new world. The observatory at Mauritia was no doubt the first astronomical observatory erected in the southern hemisphere and in the new world. After about four years Count Maurice returned to Europe; Marcgrave was sent to Angola in Africa, where he died in 1644, in the prime of life. His studies in natural history were published. He had prepared also a mathematical and astronomical manuscript, *Progymnastica mathematica Americana,* which was sent to Europe, but lost there. Lalande[18] states that he had seen notices of Marcgrave's observations in manuscripts of Delisle and that Flamsteed had examined some of Marcgrave's observations. With the death of young Marcgrave there passed away a life full of zeal and promise, and his observatory ceased to function as a temple of research.

Oakes at Harvard College. In the North American colonies came somewhat later the observations of Uriah Oakes, who graduated at Harvard College in 1649. While still very young he published a set of astronomical calculations at Cambridge. In allusion to his size, this genial and bright young man (later President of Harvard College) attached to his calculations the motto, *parvum parva decent,*

sed inest sui gratia parvis (small things befit the small, yet have a charm their own).

Brattle using Halley's Quadrant at Harvard. At Boston, Mass., Thomas Brattle,[19] a graduate of Harvard, observed eclipses of the sun in 1694—1703 which, compared with simultaneous observations taken at London, yielded 70° 45′ as the difference in longitude between Cambridge and London. This value is only about 15′ short of the correct value—a remarkably accurate determination for that time. In 1783, Joseph Willard, President of Harvard College, published a still better value, 71° 7′ 40″, which was somewhat in excess of modern determinations.

In observing the solar eclipse of June 12, 1694, at Cambridge, Mass., Brattle used a brass quadrant and telescopic sights. On December 12, 1703, he used the same brass quadrant for measuring the altitudes of stars, taken for the purpose of checking the time records obtained from the use of a ring dial and the rising of the sun. This brass quadrant was the instrument that belonged to Harvard College, and was "the very same Dr. Halley used at St. Helena."[20] In 1676, Edmund Halley, at the age of twenty, had gone to St. Helena to prepare a catalogue of the stars of the southern hemisphere, remaining at this then unique task for over two years. The brass quadrant which he then used became later the property of Harvard College. It was two feet in radius and was used by John Winthrop in 1740.

Richer in Cayenne. Our last seventeenth century notice relates to the French astronomer and physicist Jean Richer, who in 1672, secured data at Cayenne in French Guiana, for the determination of the parallax of Mars, corresponding observations on Mars being taken by Dominico Cassini at Paris. His pendulum experiments made at this time will be mentioned later.

Louis Feuillée. At the opening of the eighteenth century,

by order of the French Academy of Sciences, Father Louis Feuillée, a learned Franciscan and pupil of the astronomer G. D. Cassini, made observations of longitude and latitude in various places in Europe and America. He visited the Antilles and Panama in 1707—1712. In his voyage to Peru, he made observations on the longitude of Buenos Aires.[21]

Suarez in Paraguay. At this time, there were settlements at the inland of the southern part of South America, in Paraguay, a region which favored prosperity through its herds, its fruits and its tobacco. In that region the Jesuits had wandered and they paid some attention to astronomy. Eclipses were observed by F. Bonaventura Suarez.[22] He observed a solar eclipse on November 5, 1706, "with a five-foot telescope and a pendulum vibrating seconds, with an equal motion, and rectified to true time by the altitude of the fixt stars." In 1728 "a tube of 10 foot" was used; in 1729 the motions of the satellites of Jupiter were watched with a tube of 13 foot; there was a conjunction of the first and second satellites, so that "both stars seemed to be but one." Humboldt states that Suarez, a "little known astronomer," placed Mexico 3 hours and 13 minutes west of his observatory and his observatory 3 hours 52 minutes and 23 seconds west of Paris, thus locating Mexico 7 hours 5 minutes 23 seconds west of Paris—a result considerably in excess of modern figures. Astronomical data taken in Paraguay were utilized in the construction of maps of the region. In 1767, the Jesuits were driven out of Paraguay, and astronomical work ceased. The expulsion of the Jesuits from the various Spanish colonies in South America, deprived them of their ablest and most effective teachers, and far-sighted furtherers of intellectual life in these new regions.[23]

Laval at the Gulf Coast. As an example of the difficulties encountered as late at the eighteenth century in avoiding

gross errors in the fixing of longitudes, even after the clock and telescope were available, we cite a French observation near the mouth of the Mississippi. The French king sent the Jesuit Father Antoine J. Laval, a man of long experience in astronomical observation, to the Mississippi region to gather data for improved navigation and better maps. Though valuable in other respects, his maps showed wrong longitudes. On July 24, 1720, Laval observed the time of immersion of Jupiter's first satellite at Dauphine Isle, an island near the Alabama coast, which yielded as the longitude of that island 103° and some minutes west of Paris. Claude Delisle[24] criticized Laval's work, pointing out that 103° exceeded the previous estimate of Pitergos by 4°, of van Keulen by 6½°, of Delisle himself by 11°. If one considers that at the equator one degree means about 69½ miles, it is apparent that the location of Dauphine Isle was uncertain to the extent of many hundred miles. The same uncertainty affected the longitude of other points on the Gulf Coast. As a matter of fact, all of the above estimates were in excess; Dauphine Isle is about 90° 30′ west of Paris.

Brattle and Kearsly using ring-dials. We have already spoken of the early observations of Thomas Brattle of Boston, and of his use of Halley's quadrant. A less pretentious instrument of Brattle's was a ring-dial which he used in observing the eclipse of the moon at Cambridge in New England, February 11, 1700. "My clock was set by Ring-Dial about Nine of the Clock in the Morning, as exactly as I could judge; and the Observation was made with my 4½ Foot Telescope, with all four Glasses in it."[25] In the same way, three years later, Brattle reports: "I set my clock with the greatest exactness I could the morning preceding the eclipse of the moon, Dec. 12, 1703, at Cambridge, Mass. both from my Ring-Dial and the Rising of the Sun."[26] We have seen that the ring-dial was used at nearly the same time by Kino at the junction of the

Colorado and Gila rivers in south-western Arizona. Over thirty years later, at Philadelphia, Dr. Kearsly observed the eclipse of the sun, February 18, 1738. "I rectified my clock by one of Heath's large ring-dials."[27] Thomas Heath was a mathematical instrument maker in London who published in 1735, in conjunction with J. Mason, a booklet, "The Description and use of a new astronomical instrument, for taking altitudes of the sun and stars at sea, without a horizon."

Robie and Danforth in Massachusetts. Two other Harvard graduates who, like Brattle, took astronomical observations for the love of the art, were Samuel Danforth and Thomas Robie. Robie[28] noted the times of immersion and emersion of Jupiter's first satellite in 1717, and determined the longitude of Harvard as 4 hours and 45 minutes west of Upminster. He observed the lunar eclipse of March 15, 1717, with "a 24-foot telescope." Comparing his data with those of Cassini and De la Hire, of Paris, he found Cambridge 4 hours 55 minutes and 50 seconds west of Paris.[29] The 24-foot instrument was of a Huygens type and was constructed before the day of achromatic lenses. It may be worth while to recall to the reader the reason for the use at the time of refracting telescopes of great length—some even 100 or 200 feet, or more.

Huygens type of Telescope. The linear magnifying power of a telescope is the ratio of the focal length of the objective and the focal length of the eye-piece. To enlarge the magnifying power of the instrument one may increase the focal length of the objective or decrease the focal length of the eye-piece, or both. But powerful eye-pieces of short length could not be successfully constructed at that time because of the blurring of the image by color-effects. Nor were the images formed by object glasses of short focal length in those days of the quality that would bear much magnifying. Achromatic lenses were invented much later.

On the other hand, the focal length of the objective could be *increased* without serious chromatic effects. For this reason, objective lenses of great focal length were constructed. In the British Museum there are three object glasses[30] completed by Constantine Huygens, in June 1686, whose focal lengths are respectively 122 feet, 170 feet, and 210 feet. The first was the objective of an aerial telescope which, with an eye-glass of a focal length of six inches, Huygens presented to the Royal Society of London in 1691. The great difficulty encountered in using these tube-less telescopes was "to get the eye and object-glasses of these unwieldy machines *married*, or brought parallel to each other for perfect vision." We are told that in 1710, when Edmund Halley was with the astronomer Hevelius at Danzig, Halley "discovered that they could not see or observe anything with his (Hevelius') telescope of 300 feet, and that his other telescopes were useless, because on account of their length, the centers of the lenses cannot be brought into a straight line."[31] In England, telescopes of extreme focal length seldom found favor. On December 2, 1733, James Bradley wrote to James Stirling that he had used the Royal Society glass of 123 feet focus in measuring diameters of Jupiter.

Robie, and Danforth who was minister at Roxburg, together observed the solar eclipse at Cambridge, N. E., in November 27, 1722; Robie also watched the transit of Mercury over the disc of the sun, on October 29, 1723. Robie described both events in an unaddressed letter, probably meant for Governor William Burnet.[32] Robie ventured to write it because of "your excellency's very great Knowledge in and Affection to, Astronomy, and also of your great pleasure in receiving any Astronomical Observations." That Robie computed as well as observed, appears from the following part of the letter: "There will be a large Solar Eclipse in May next, Central and total in ye South west of England, as doubtless yr Excellency well knows,

and so I only add yt it will be here abt 7 or 8 dig. as I remember I made it when I calculated it some years agoe. I have long wish'd for good Observations to be made at New York, but dispared, till I heard of yr Excellency's disposition, and now I hope ye Longitude between here and there will be established wch will be a public Service."

Contemporary[33] with Brattle and Robie in Boston were Sir William Keith in Philadelphia and Cadwallader Colden in New York, who made latitude and longitude observations of other important centers of population and commerce.

John Winthrop. A distinguished figure in the mathematical sciences in the middle of the eighteenth century at Harvard was John Winthrop. His scientific standing in New England corresponded to that occupied in the previous century by Sigüenza in Mexico. John Winthrop[34] (1714-1779), graduated from Harvard College at the age of eighteen, and at twenty-four was elected Hollis professor of Mathematics and Natural Philosophy. He contributed to the *Philosophical Transactions* of London. In all, fourteen of his papers were printed. At first his articles were along the line of natural history: "Forests of a sort of dwarf oak" that were "most difficult to break up at first with a plough," "on a certain tree with little knobs" containing a liquid "of a very sanative nature," on the "down of the cotton tree" that is "not fit to spin," on the culture of "maize." After 1739 when he began astronomical observations, his papers were on astronomy, natural philosophy and mathematics. He lectured on earthquakes and, in 1759, when Halley's comet returned, on comets. Winthrop was an inspiring teacher. Count Rumford as a boy of seventeen walked eight miles from Woburn to Cambridge to attend Winthrop's lectures on natural philosophy. Winthrop was in correspondence with Benjamin Franklin. We are told that Franklin successfully recommended Winthrop for an honor-

ary degree at the University of Edinburgh after he had been rejected by Oxford because he was a Dissenter.[35]

Winthrop began observing in 1739; on April 27, 1740, he observed the transit of Mercury with the 24-foot telescope that Robie and others had used. He said: The instruments used "were only those I had received from my Predecessor Mr. Is. Greenwood, and are the same that are mentioned by the late Mr. Thomas Robie, being a 24 Foot Telescope, another 8 Foot, and a brass Quadrant 2 Foot Radius, fitted with telescopic sights, and having Cross-Haires fixed in the focus of the Glasses." On December 21 of the same year, Winthrop observed an eclipse of the moon.[36]

Burning of Harvard Library. The 24-foot telescope had rendered good service at Harvard for many years, but finally its career was doomed. It was lost in the fire which destroyed the Harvard Library building, in 1764.[37]

It is worth while to quote the somewhat comprehensive statement of the equipment for the exact sciences which was destroyed in the Harvard fire. "For Astronomy," it is stated,[38] "we had before been supplied by Mr. Hollis with telescopes of different lengths, one of 24 feet; and a brass quadrant of two feet radius, carrying a telescope of a greater length, which formerly belonged to the celebrated Dr. Halley. We had also the most useful instrument for dialing; and for surveying, a brass semi-circle, with plain sights, and magnetic needles. Also a curious telescope, with a complete apparatus for taking the difference of leveling. From a number of gentlemen of the province the following additions were received: a fine reflecting telescope of different magnifying powers, and adapted to different observations. Microscopes of the several sorts now in use; Hadley quadrant, fitted in a new manner, a nice variation compass, and dipping needles with instruments for the several magnetical and electrical experiments,—all new

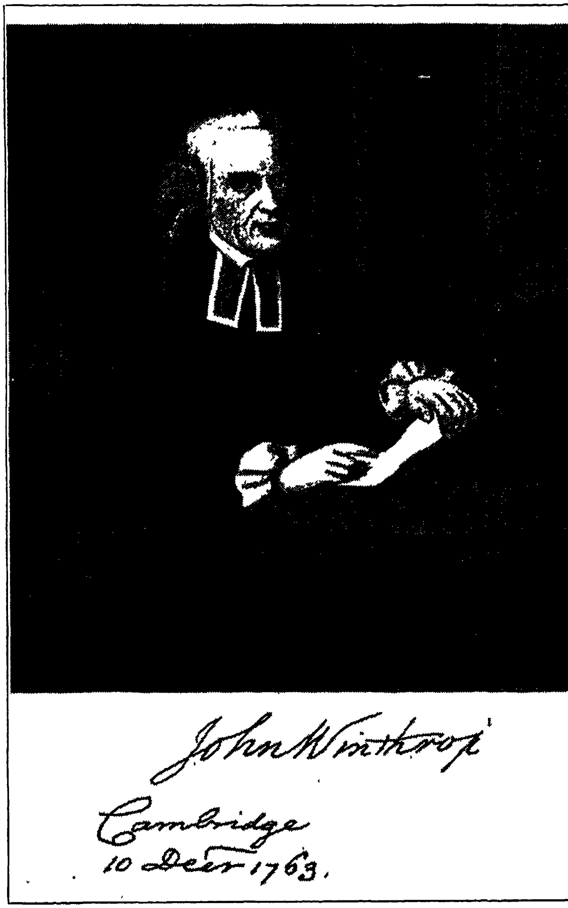

Fig. 13. John Winthrop and his Reflecting telescope. Copied from Justin Winsor's Memorial History of Boston, Vol. 4. 1881, p. 494.

and of excellent workmanship,—and all destroyed in the burning of Harvard Hall in 1764."

An appeal for aid was sent out at this crisis and in a few years a new and improved equipment was secured. In particular, Harvard College secured another Huygens telescope, larger than the first, and a Gregorian reflector. The glasses for the refracting telescope did not reach the college in time for the observations of the transit of Venus, in 1769, but they were used at the Norriton Observatory in Philadelphia. Concerning this we read: "A Refractor of 42 f., its magnifying power about 140. The glasses were sent from London with the large Reflector, and belonged to Harvard College, New England; but as they did not arrive in time enough to be sent to that place before the Transit, they were fitted up here by Mr. Rittenhouse and used by Mr. Lukens."[39] This is the longest refracting telescope ever used in the American colonies. Another refracting telescope, of unusual size in those days, was a twenty-four foot instrument that was used in Philadelphia, "belonging to Miss Norris."[40] David Rittenhouse made a refractor that had "an object glass[41] of thirty-six foot focus."

The Reflecting Telescope. The portrait of John Winthrop (Fig. 13) exhibits him with a reflecting telescope. The rise of this type of instrument, and the rivalry that has existed ever since the time of Sir Isaac Newton between the reflecting telescope and the refracting telescope constitute an interesting chapter. The reflector possessed points of superiority over the old time refractor. The first reflecting telescope was made by Newton with his own hands. In 1668 he produced a tiny speculum. Soon after, he made a larger and better reflector which he presented to the Royal Society of London. It possessed advantages over the refractor with its blurring chromatic fringes. The reflector was quite free from that defect. At this time a slightly

different type of reflector, designed by James Gregory of Edinburgh as early as 1663, came to be manufactured and used. In the "Gregorian" form the rays are brought to a focus by the large reflecting mirror and then by a small concave mirror are thrown back through a central aperture in the large mirror, behind which the eye-piece is fixed. In the "Newtonian" form the light is reflected to one side of the tube. The reflecting telescope was greatly developed during the years 1732-'68 by James Short, a mathematical instrument maker at Edinburgh, and later by William Herschel and others. Herschel constructed a seven-foot reflector in 1775 and a forty-foot reflector in 1789. Several reflecting telescopes were brought to the American colonies. In 1764 Professor Samuel Williams of Harvard, a pupil of John Winthrop, observed at Waltham, Mass., a lunar eclipse, using a reflecting telescope about four feet in length; and the clock was adjusted by a meridian line, and corresponding altitudes of the sun.[42] In observing a solar eclipse on October 27, 1780, at the east side of Long Island, two reflectors manufactured by Short were used, the focal length of one being one foot and of the other two feet.

A Watkins and Smith 3-foot reflector (See Fig. 14) with a Dolland "microscope" or heliometer was used in 1769 at Providence, Rhode Island, by Benjamin West.[43] Yale College possessed a Gregorian telescope 3½ feet long, mounted on a brass stand[44] and a similar one 2½ feet. The former was lost with Professor Alexander M. Fisher who in 1822 was taking it to England for the purpose of having it repaired.

A Gregorian reflector, made by the English instrument maker Nairne, was used by Dr. William Smith of Philadelphia in 1769. It was described as of "about 2 feet focal length, with Dolland's micrometer," having four different magnifying powers. viz., 55, 95, 130, and 200 times.[45] Another Nairne reflector "magnifying 55 times" was used

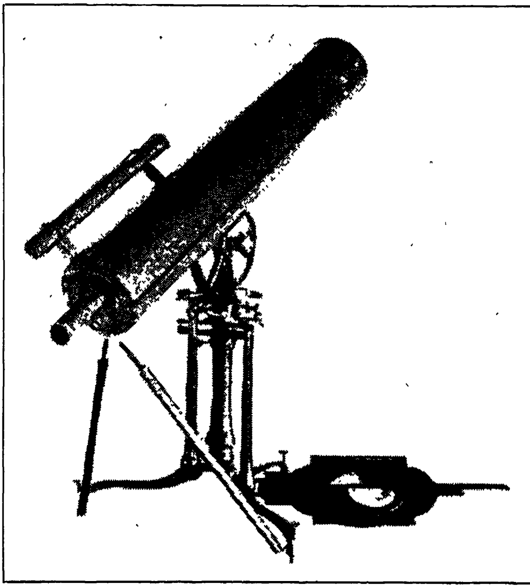

Fig. 14. The Reflector with "microscope" attached, used by Benjamin West. The author is indebted to Mr. F. E. Brasch.

in the observation of a lunar eclipse, May 29, 1779, at Bradford, Pa., " . . . the times were shewn by a good clock, carefully adjusted by equal altiudes of the sun, the day before and the day after the eclipse."[46]

Another Philadelphia observer (Joseph Shippen) used a "new reflecting telescope made by Mr. George Adams, whose tube is two feet and half an inch long, its aperture 415 inches diameter and its magnifying power about 90 times."[47] These accounts indicate that eight or more reflectors, most of them small, were used in the neighborhoods of Boston, New York and Philadelphia in the eighteenth century, since 1764.

Achromatic Lens. But the reflecting telescope did not retain permanent supremacy over the refractor. The construction of achromatic lenses, begun by Dollond about 1758, was epoch-making, and gave the refracting telescope renewed power. The achromatic lens was free of the blurring color effects of the earlier lenses. Some early Dollond instruments came to be used in America. Samuel Holland,[48] His Majesty's Surveyor General of Lands for the Northern District of North America, used a Dollond 12-foot refracting telescope, a Bird's astronomical quadrant, and a Graham clock with gridiron pendulum, for the determination of longitudes and latitudes of places in or near Canada, including the Island of St. John, Holland's house near Quebec, Kittery Point in Maine, Portsmouth in New Hampshire. The longitudes were found by the comparison of the times of immersion and emersion of Jupiter's first satellite at each of the places named, with the corresponding times at Greenwich.

A field-glass of the Dollond make was used by George Washington[49] when commander-in-chief during the Revolution.

During the observations of the solar eclipse on April 12, 1782, Professor Williams, of Harvard College, used at

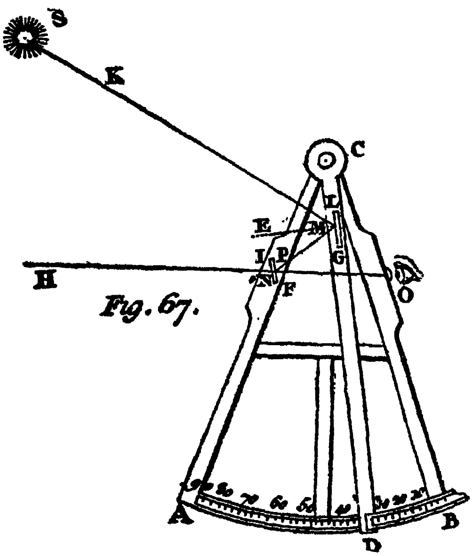

Fig. 15. Shows the use of Hadley's Quadrant, when the observer is facing the object observed. (Figs. 15 and 16 are taken from Bouguer's *Nouveau Traité de Navigation,* Paris 1753, planches X XI.)

Cambridge, Massachusetts, an achromatic telescope magnifying 90 times.[50] On November 12 of the same year he observed the transit of Mercury with "an achromatic telescope made by Nairne, with a magnifying power of 150." This is probably the preceding instrument with a more powerful eye-piece attached. Joseph Willard, president of Harvard College, observed the transit of Mercury, November 5, 1789, with an achromatic telescope 3½ feet long, magnifying 90 times.[51] Willard found Harvard Hall to be 4^h 44^m 31^s west of Greenwich, a result, according to Joseph Lovering "probably as exact as that for any two places on the earth at that time, if determined without the aid of geodesy." Andrew Ellicott in his observations made about 1798 on the boundary between the United States and the

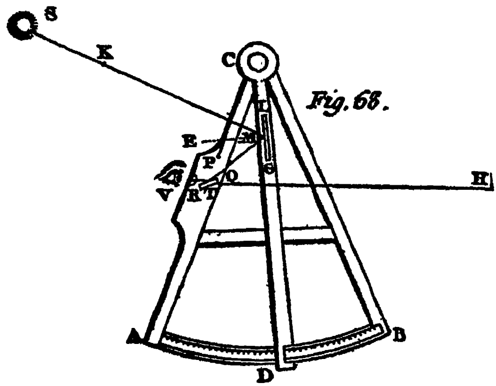

Fig. 16. Shows the use of Hadley's Quadrant when the observer is turning his back to the object observed.

Spanish possessions, used among other instruments "a large achromatic telescope made by Mr. Dollond of London, which exclusive of a terrestrial eyepiece which magnifies about 60 times, has three other eyepieces for celestial purposes, the magnifying powers (of which) are 120, 200 and 300."[52] Ellicott adds: "This instrument for producing a well defined clear image is exceeded by but few reflectors."

The Reflecting Quadrant. The first invention made in America which constituted a radical improvement in nautical equipment was the reflecting quadrant of Thomas Godfrey of Philadelphia. As in the case of most inventions or discoveries, the credit in this case cannot be given exclusively to one man. In England, John Hadley, a friend of Newton, had accomplished the same. But Hadley was anticipated by Newton himself, though the latter never published his design nor adopted it in practice.

These instruments were not strictly quadrants, but octants, because actually they were only the eighth part of a circle, though they measured 90° by reason of the reflected ray being deflected through twice the angular displacement of

the index of the quadrant. Hadley's quadrant is shown in Figs. 15 and 16.

We have nowhere been able to find a drawing of Godfrey's instrument. He invented it in 1730 and an account of it, in an article entitled, "Improvement of Davis's Quadrant,"[53] written by J. Logan, was published in the Philosophical Transactions of London in 1734. Hadley made his invention in 1731, before he had seen an account of Godfrey's instrument. What purported to be an improvement in the construction of "Godfrey's double reflecting quadrant" was described by John Ewing[54] of Philadelphia and illustrated by a drawing. But Ewing's design received no attention. Nor are we able to learn that Godfrey's instrument was widely used. Godfrey's facilities for manufacture must have been very limited, as compared with those of instrument makers in London. The instrument came to be generally known as "Hadley's Quadrant." Some of these quadrants were made of wood. The instrument was intended mainly for taking altitudes of heavenly bodies above the visible horizon, the observer either facing the object observed or turning his back to it. Figs. 15 and 16 illustrate the two modes of taking observations. Sisson's 2½ foot quadrants of the Hadley type were used by David Rittenhouse at Philadelphia in 1768[55] and by observers of the solar eclipse at Long Island in October, 1780.[56]

"Hadley's octant" as the instrument was sometimes called, was repeatedly used by Joseph Willard, president of Harvard College, about 1780,[57] also by Reverend Manasseh Cutler at Ipswich, Mass., on March 29, 1782.[58]

Thomas Godfrey was one of a number of noted mathematicians and astronomers on this side of the Atlantic who were self-taught. He was a glazier by trade. He pursued the study of Latin that he might read Newton's *Principia,* a work not then available in English. Some personal characteristics of Godfrey are known through Benjamin

Fig. 17. David Rittenhouse.

Franklin: "I continued to board with Godfrey, who lived in part of my house with his wife and children, and had one side of the shop for his glazier's business, though he worked but little, being always absorbed in mathematics." In 1727 when Franklin formed the club *Junto* for mutual improvement, "one of the first members . . . was Thomas Godfrey, a self-taught mathematician, great in a way, and afterwards inventor of what is now called Hadley's Quadrant. But he knew little out of his way, and was not a pleasing companion, as, like most great mathematicians I have met with, he expected universal precision in everything said, and was forever denying and distinguishing upon trifles, to the disturbance of all conversation."

David Rittenhouse. Another Philadelphian, and self-taught mathematician was David Rittenhouse. We have already referred to him as a mathematician. He was a clock and mechanical-instrument maker. Many instruments

of this type, used in American surveys and observations, were made by him. He invented the "collimator," a device "for obtaining a meridian mark without going far away;" later it came back from Germany, where it was re-invented. He introduced the use of spider threads in telescopes in 1780 and later, spider webs were used by the well known instrument maker, Edward Troughton, in London. We know that spider threads had been *suggested* in 1755, by Professor Felice Fontana of Florence. In the rooms of the American Philosophical Society are exhibited an astronomical clock and a transit instrument (Fig.18) made by Rittenhouse.

Rittenhouse ranks as the foremost observational astronomer of the eighteenth century in America.

First total Solar eclipse expedition. Records of observations of solar and lunar eclipses in the years 1761 to 1784, made by Samuel Williams, professor at Harvard College, Joseph Willard, president of Harvard, and by others are published in the first volume (1785) of the Memoirs of the American Academy of Arts and Sciences in Boston.[59] Especially noteworthy is the expedition to Long Island in Penobscot Bay, Maine, to observe the solar eclipse on Oct. 27, 1780, which was total there. It is the earliest total eclipse expedition organized in America. It was undertaken during war time. Representatives of the American Academy of Arts and Sciences and of Harvard College solicited the Commonwealth "that a vessel might be prepared to convey proper observers to Penobscot-Bay, and that application might be made to the officer who commanded the British garrison there, for leave to take a situation convenient for this purpose. Though involved in all the calamities and distresses of a severe war, the government discovered all the attention and readiness to promote the cause of science which could have been expected in the most peaceable and prosperous times." The expedition was under the direction

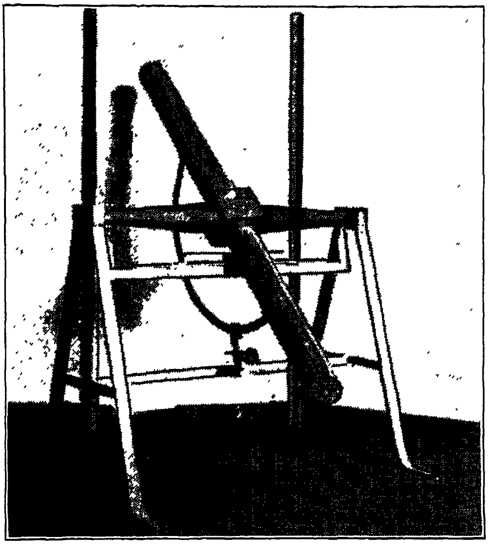

Fig. 18. David Rittenhouse's transit instrument used in 1796. Now kept in the Library of the American Philosophical Society in Philadelphia. Mr. F. E. Brasch kindly supplied this photograph to the writer.

of Samuel Williams, who was assisted by several members of the Harvard faculty and by students. Williams noted during the eclipse "luminous drops," the phenomenon now known as "Baily's beads" from Baily's observation of 1836 that part of the arc of the moon's circumference suddenly began to look like a string of bright beads, just before the moon appeared well inside the limb of the sun.[60]

Among other observations of this eclipse were those at Beverly, by President Willard, and at Cambridge by Caleb Gannett.

Eighteenth Century Work in Mexico. Of half a dozen or more noted Mexicans who busied themselves with geographic determinations, in this century, the earliest is José Rivera who found the position of the great mining town Zacatecas, of which place he published a description in 1732.[61] He used an astrolabe, and a quadrant three yards in diameter. Although he took two years for his determinations and followed several modes of procedure, his latitude for Zacatecas was 16′ in excess of the best modern figures, and the difference in longitude between Zacatecas and Mexico was over 1° in excess. Nor is great reliability assigned to the data of Antonio de Villaseñor y Sanchez. for the position of Mexico, given in his two- volume *Theatro Americano,* published at Mexico in 1746-'48.

Great zeal in scientific research was displayed by Father José Alzate y Ramirez. As will be seen more fully later, he worked in many fields of science—practical astronomy, physics, meteorology, natural history. In astronomical observations he was not particularly successful. "This Mexican ecclesiastic" says Humboldt,[62] "whom the academy of Paris named one of their correspondents, displayed more zeal than solidity in his researches: he embraced too many things at once. His acquisitions were very inferior to those of Velazquez and Gama, two of his countrymen, whose true merit has never been sufficiently known in Europe. . . .

De Lalande finds by the transit of Venus, observed in 1769 by Alzate, $6^{h.}$ 50′ 1″ for the longitude of Mexico. But in 1786, in a note which accompanies the plan of the environs of Mexico, drawn up by Sigüenza, and engraved at Mexico, Alzate fixes the longitude at 100° 30′ 0″ = 6^{h} 42′ 0″, adding that this last result, *the surest of all,* is founded on more than 25 eclipses of satellites communicated to the academy of Paris.[63] There is consequently a difference of more than two degrees between the different observations of M. Alzate. . . . It is to be presumed that the observer was not exact as to the time."

Joaquin Velazquez. The ablest practical astronomer of Mexico in the eighteenth century was Joaquin Velazquez Cárdenas y León. He was born near the Indian village Tizicapan in 1732, and died in Mexico in 1786, "full of honors."[64] In his youth, the works of Newton and Bacon fell into his hands, Not finding in Mexico the needed astronomical instruments, he followed the course of many others in the western hemisphere and constructed some of them himself. Later in life, he ordered some delicate instruments from England, paying for them out of his own earnings[65]. Humboldt says that Velazquez used in 1773 in a survey for a map of Mexico "an excellent English theodolite of ten inches diameter, provided with two glasses twenty-eight inches in length."[67] When the Mining College was established in Mexico, which is the forerunner of the present National School of Engineers, Velazquez became one of three prominent professors who gave character to the institution.[66] He was sent on an expedition to lower California, in 1768, where he took astronomical observations. He prepared to observe the transit of Venus in 1769, of which more later on. The French astronomer Chappe observed this transit in Lower California, and soon after died there. Chappe's instruments fell into Velazquez's hands; he himself says: "Nevertheless I stayed in

California to take possession of the mathematical instruments of Chappe, for I had not been able to ascertain that steps were under way for their safe return. They were the only good ones that I had seen and used all my life. . . . They were in fact the best manufactured in Europe, executed with the greatest care by artists in London and Paris. With these I made a large number of different observations in various parts of California and I had the satisfaction of comparison with those I had taken the year before, concerning which there had been disagreement. Finally, after much difficult and dangerous travel, having returned on Dec. 11, 1770, to Mexico, where the instruments remained in my possession for some time, I had at last the satisfaction to observe the true latitude of Mexico, desired for so long. Thus, from March 25 to April 10, 1771, in the street of San Lorenzo . . . with a quadrant of 2½ ft. radius, supplied with an achromatic telescope, and an excellent micrometer, of the make of Mr. Cavinet, the instrument manufacturer of the royal academy of sciences, I being accompanied always by Dr. José Ignacio Bartolache, and most of the time also by Antonio Gama, a mathematician of this city, we observed eight times the meridian altitude of the center of the sun and five times the transit of the star of the first magnitude, called Spica Virgines, . . . using ephemeries and tables of Mr. de la Caille (than which there are today no better in Europe), for computing the declination and the rest of the corrections of these stars, we found the north latitude of Mexico to be 19° 25′ 58″.[68] . . . In the spring of 1771 at the same house in San Lorenzo street, . . . with a Dollond achromatic telescope and a well regulated pendulum of Fernando Berthoud, I observed almost always in the company of Dr. Bartolache and Antonio Gama, the first and second satellites of Jupiter. At the residence of the latter, in the street of del Reloj, I observed with him, by the aid of a good 10-foot telescope

. . . and the difference in time between Mexico and Paris was found to be 6^h 46′ 55.″[69] This result is still 1′ 5.8″ of time in excess of modern values, but it is far better than the figures adopted in European publications at the close of the eighteenth century.

In the last quarter of the eighteenth century, there was great progress in England and France in the manufacture of delicate astronomical and nautical instruments. Chappe's instruments, so greatly admired by Velazquez, were of an older make and Humboldt, about a quarter of a century after the death of Chappe, spoke disparagingly of them. "Provided with a large quadrant of three feet radius, Chappe found the latitude of San Jose (Mexico), by Arcturus, to be 23° 4′ 1″; by Antares, 23° 3′ 12″. . . . I cite these examples, not for the sake of discrediting astronomers who have so many titles to our esteem, but to prove that a sextant of five inches radius would have been more useful to the Abbé Chappe than his quadrant of three feet radius, difficult both to place and to verify." Of the small quadrant of Chappe, Humboldt says after examining it, "I am by no means astonished that, with so imperfect an instrument, his observations were so inaccurate."[70]

Humboldt's own determination of the longitude of Mexico is 6^h 45′ 42″ or 101° 25′ 30″ west of Paris, a result 1′ 48″ of arc short of the modern figure of 6^h 45′ 49.2″ or 101° 27′ 18″ due to Francisco Diaz Corarrúbias.[17]

Leon de Gama observed the solar eclipse of June 24, 1778, and obtained a position for Mexico in close agreement with those of Velazquez.[72]

A Spanish naval officer, Dionisio Galiano, "one of the most able astronomers of the royal marine," says Humboldt,[73] "had also found out the true position of Mexico, when he traversed the Kingdom in 1791, to join the expedition of Malaspina. His observations consisted of two immersions of satellites and the end of a lunar eclipse; they give 6^h

45′ 30″ = 101° 22′ 34″ as Mexico's longitude west of Paris.

Longitudinal error and a popular fright. The best early determinations of the position of Mexico, namely that of Rodriguez of the seventeenth century, and those of Velazquez, Gama and Galiano in the eighteenth century, did not become generally known to Europeans and were not entered upon the maps issued at the time. The accepted results due to Alzate and some others placed Mexico much too far west, "in the South Sea" or Pacific Ocean, as Velazquez expressed it.

Humboldt[74] narrates one discomfiture resulting from this false longitude: "The false position so long attributed to the capital of New Spain produced a remarkable effect at the time of the sun's eclipse, 21st Feb. 1803. The eclipse was total, and threw the public into consternation, because the almanac of Mexico, calculated on the supposition of 6^h 49′ 43″ of longitude, had announced it as scarcely visible. The learned astronomer of the Havanah, Don Antonio Roberedo, recalculated this eclipse according to my observations of longitude."[75] He found that the eclipse would not have been total if the longitude of Mexico were farther west than 6^h 46′ 35.4″ = 101° 38′ 49″.

Humboldt's travels through Mexico, his personal influence, and his *Political Essay on the Kingdom of New Spain,* contributed much toward the advancement of Mexico, by their stimulus for further development, especially of the mining industry.[76]

Pseudo Scientific Publications. The American press of the twentieth century frequently contains items astrological in character. Little marvel, therefore, if two hundred years ago, pseudo scientific books were issued in America. At Lima, Peru, there was printed Juan de Figueroa's *Opvscvlo de astrologia,* in 1660, which was only about a third of a century after general Wallenstein in Germany had engaged the services of John Kepler to make astrological predictions

for him. Later, in Peru, came the writings of Juan de Barrenechea, "a substitute of the professor of mathematics in the university at Lima," who published in 1725 his *Relox astronomico de temblores de la tierra,* and in 1734 his *Nueva observacion astronomica del periodo tragico de los temblores.* The French astronomer Bouguer[77] tells how Barrenechea in 1725 pretended to prognosticate the periods of earthquakes and volcanic irruptions by indicating "the fatal hours during which they were to be apprehended," namely, "the six hours and some minutes the moon takes up to pass the horary circle betwen three and nine," other hours being exempt. According to Bouguer, the book of 1734 gives "a tragic period to serve as a rule to distinguish the years subject to similar accidents;" nothing need be apprehended except when the horns of the moon are found in the malignant signs of Scorpion or Amphora. As in Peru there are few weeks in which some slight shock of earthquake is not felt, astrologers were frequently in a position to boast that their predictions had become true. But Bouguer points out that at the time of the severe earthquake which destroyed Lima in 1746 the horns of the moon were not in the signs of Scorpion or Amphora, and the moon was not passing the horary circle between three and nine.

1. J. Winsor, *Narrative and Critical History of America,* Vol. II, 1886, p. 96, 99.

2. Alexander von Humboldt, *Cosmos,* Edition by E. Sabine, Vol. 2, London, 1849, p. 282.

3. Drawings of Arabic astrolabes are given in Joh. A. Repsold, *Zur Geschichte der Astronomischen Messwerkzeuge von Purbach bis Reichenbach,* Leipzig, 1908, p. 7. See also p. 14-16, 74.

4. R. T. Gunther, *Early Science in Oxford,* Vol. II, Oxford, 1923, p. 228.

5. R. T. Gunther, *loc. cit.,* Vol. II,, p. 227.

6. R. Wolf, *Handbuch der Astronomie,* Zürich, 1892, Vol. 2, p. 44. J. A. Repsold, *op cit.,* p. 12, 13, 17, 74, gives additional historical details. See also J. Bensaude, *L'Astronomie nautique au Portugal a l'époque des grandes découvertes,* Bern, 1912; J. L. E. Dreyer in

Studies in the History and Method of Science, edited by Charles Singer, Vol. II, Oxford, 1921, p. 118.

7. Filson Young, *Christopher Columbus and the New World of his Discovery,* Vol. II. Philadelphia, 1906, p. 298 (article by Earl of Dunraven); Breusing, *Zeitsch. d. Gesell. für Erdk.,* Berlin, Bd. IV, p. 99; Justin Winsor, *Narrative and Critical History of America,* Vol. II, Boston and New York, 1886, p. 93-128.

8. E. Gelcich, *Die Instrumente und die Wissenschaftlichen Hülfsmittel der Nautik zur Zeit der Grossen Länderentdeckung, Separatabdruck aus Festschrift der Hamburgischen Amerika Feier,* 1892, p. 47.

9. *Bibliotheca Mathematica,* N. S. Vol. 4, 1904, p. 77 ff; Vol. 14, 1913-1914, p. 261.

10. De La Condamine: *Relation abrégée d'un voyage fait dans l'intérieur de l'Amérique Méridionale,* Paris, 1745, p. 13 et seq.

11. Humboldt, *Political Essay on the Kingdom of New Spain,* transl. by J. Black, Vol. 1, London, p. XXXV, XXXVII.

12. Manuel Orozco y Berra, *Apuntes para la historia de la geografia en México,* Mexico, 1881, p. 150, 151.

13. Manuel Orozco y Berra, op. cit., p. 312, 313.

14. Manuel Orozco y Berra, op. cit., p. 221, 222, 312.

15. O. H. Marshall: "Champlain's Astrolabe" in *Magazine of American History,* Vol. III, p. 179. See also A. J. Russell *On Champlain's Astrolabe,* Montreal, 1879; Slafter's edition of *Champlain's Voyages,* III, pp. 64-66; H. W. Hill, *The Champlain Tercentenary,* Albany, 1911, p. 57.

16. R. G. Thwaites, *The Jesuit Relations and Allied Documents,* Vol. 64, Cleveland, 1900, p. 149.

17. E. W. Gudger, *Popular Science Monthly,* Vol. 81, 1912, p. 250-274.

18. Lalande, *Astronomie,* 2. Éd., Vol. 2, p. 160; Vol. 3, p. 142.

19. For a biographical sketch of Brattle, see Justin Winsor's *Memorial History of Boston,* Vol. IV, 1881, p. 491.

20. *Philosophical Transactions,* Abridged, London, 1734,, Part I, p. 173.

21. *Philosophical Transactions,* Abridged, Vol. 6, p. 407..

22. Astronomical data were communicated in 1747, to the Royal Society of London. See *Philosophical Transactions,* Abridged, Vol. 10, Part I, London, 1756, pp. 118-124.

23. Bernard Moses, *Spain's Declining Power in South America,* 1919, p. IX.

24. *Mémoires de l'académie royale des sciences, année* 1726, pp. 249-258.

25. *Philosophical Transactions,* London, No. 202, p. 1633.

26. *Loc. cit.,* No. 292, p. 1656.

27. *Loc. cit.,* No. 446, p. 121.

28. Justin Winsor, *Memorial History of Boston,* Vol. 4, 1881, p. 490, 492.

29. *Cadwallader Colden Papers,* New York Historical Society Collection, Vol. 1, 1918, p. 166. Given by W. C. Rufus in *Scientific Monthly,* Vol. 19, 1924, p. 121.

30. R. T. Gunther, *Early Science in Oxford,* Vol. 2, Oxford, 1923, p. 300-302.

31. Communication of the Savilian Professor Caswell of Oxford to Uffenbach, Oct. 6, 1710. Copied in *Catalogue of a Loan Exhibition of Early Scientific Instruments in Oxford.* May, 1919, p. 18.

32. The letter is given in full by W. C. Rufus, *loc. cit.,* p. 123. It was found among the *Cadwallader Colden papers,* Vol. 1, 1918, p. 159.

33. W. C. Rufus, *loc. cit.,* p. 122.

34. See Frederick E. Brasch, "John Winthrop" in *Publications of the Astronomical Society of the Pacific,* No. 165, August-October, 1916.

35. *The Writings of Benjamin Franklin* by A. H. Smyth, Vol. 10, p. 204.

36. *Philosophical Transactions,* No. 471, p. 577.

37. B. Peirce, *History of Harvard University,* Cambridge, 1833, p. 286.

38. Quincy's *History of Harvard University,* Vol. II, p. 482-3.

39. *Transactions of the American Philosophical Society,* Vol. 1, 2nd Ed., 1789, p. 11.

40. Loc. cit., Vol. 1, 2nd Ed., 1789, p. 42.

41. Loc. cit. p. 11.

42. *Memoires American Academy of Arts and Sciences,* Boston, 1785,, Vol. 1, p. 82.

43. *Loc. cit.,* Vol. 1, p. 92.

44. E. Baldwin, *Annals of Yale,* New Haven, 1831, p. 260.

45. *Transactions American Philosophical Society,* Philadelphia, Vol. I, 2nd Ed., 1789, p. 11.

46. *Memoirs American Academy of Arts and Sciences,* Boston, Vol. I, p. 86.

47. *Transactions of the American Philosophical Society,* Philadelphia, Vol. I, 1789, p. 43.

48. *Philosophical Transactions,* Vol. 64 for the year 1774, Part I, London, 1774, p. 182-190.

49. C. W. Bowen, *Centennial Celebration of the Inauguration of George Washington,* New York, 1892, p. 164.

50. *Memoirs American Academy of Arts and Sciences,* Vol. I, Boston, 1785, p. 107, 113.

51. *Op. Cit.,* Vol. 2, Part I, Boston, 1793, p. 24. See also Justin Winsor, *Memorial History of Boston,* Vol. IV, 1881, p. 497.

52. *Transactions of the American Philosophical Society,* Vol. 5, Philadelphia, p. 205.

53. *Philosophical Transactions,* London, No. 435, p. 441.

54. *Transactions of the American Philosophical Society,* Vol. I, 1769-1771. Appendix, p. 21.)

55. *Transactions American Philosophical Society,* Vol. I, 2d Ed., 1789, p. 119.

56. *Memoirs American Academy Arts and Sciences,* Vol. I, Boston, 1785, p. 62, 87.

57. *Op. cit.,* Vol. I, p. 70, 129, 132.

58. *Op. cit.,* Vol. I, p. 162, 164.

59. *Memoirs of the American Academy of Arts and Sciences,* Vol. I, 1785, p. 86.

60. W. C. Rufus in *Popular Astronomy,* Vol. 29, October, 1921, p. 11.

61. Manuel Orozco y Berra, *op. cit.,* p. 321, 323.
62. Alexander de Humboldt, *Political Essay on the Kingdom of New Spain,* translated by John Black, Vol. 1, 1814, p. XXVIII, XXIX.
63. *Plano de les Arcanias the Mexico por Don Carlos de Sigüenza, reimpreso en 1786, con algunas adiciones de Don Josef Alzate.*
64. *Mexico, Its Social Evolution,* Tome I, Vol. 2, Mexico, 1900, p. 438.
65. *Loc. cit.,* p. 438.
66. *Loc. cit.,* Tome II, p. 67, 68.
67. Humboldt, *Political Essay on the Kingdom of New Spain,* transl. by J. Black, Vol. I, 1811; p. C.
68. Manuel Orozco y Berra, *op. cit.,* p. 315, 316.
69. *Op. cit.,* p. 318, 319.
70. Alexander de Humboldt, *op. cit.,* p. XXXIV.
71. Manuel Orozco y Berra, *op. cit.,* p. 221, 222 312.
72. Manuel Orozco y Berra, *op. cit.,* p. 320.
73. Alexander de Humboldt, *op. cit.,* p. XXV.
74. Alexander de Humboldt, *op. cit.,* p. XXX.
75. *Aurora, o Correo politico economico de la Havana,* 1804, No. 219, p. 13.
76. *Mexico, Its Social Evolution,* Tome II, 1900, p. 68.
77. Pierre Bouguer, Voyage to Peru, in John Pinkerton's *Voyages and Travels,* Vol. 14, London, 1813, p. 303-305.

CHAPTER III

SURVEYS AND MAPS

Nothwithstanding the interest which centers in Christopher Columbus, it is not incumbent upon us to go into details about a Map now kept in the Bibliothèque Nationale in Paris, which, according to de la Roncière's recent claim, is a map made under the direction of Columbus and revealing his plan of exploration at the time of the first voyage![1] Such a map due to Columbus would indeed be historically valuable; but competent critics are slow to accept Rongière's conclusion. The map shows the Mediterranean, the coasts of Europe and Africa south to about the latitude of Angola, and the isles of the eastern Atlantic. There is a total absence of any indication of a New World.

Nor do we attempt to give an account of very early maps of localities in the New World. At every colony some sort of map showing the coast outline, the different settlements, rivers and roads, would be made. But unless the maps indicate some accurate determinations of positions and accurate surveys, they are devoid of scientific interest. In any case, our limitations of space compel us to give only snapshots of practices and achievements, here and there. Brief reference has already been made to certain important maps—Sigüenza's general map of Mexico, a reissue of that map, in 1786, by Alzate, later maps of Mexico by Velazquez and by Humboldt, Caldas' maps of parts of Colombia, Laval's and Delisle's maps of the Gulf Coast. Maps of the Jesuit missions in the basin of the

La Plata in Argentine and Paraguay were published in 1732 at Rome.[2] Jesuit maps of Patagonia were made the basis, in 1750, for the demarcation of the territory between the Spanish and Portuguese.[3]

Sigüenza in Alabama. In 1693, at a time of French and Spanish rivalry in the Gulf region of the United States, Cárlos de Sigüenza y Góngora, the noted professor of the University of Mexico, was sent on an expedition with a party to draw maps of Pensacola Bay in Alabama and particularly to determine the possibility of building fortifications that would command the entrance to the bay. While Sigüenza was computing, trigonometrically, the distance between the nearest points, the other members of the party were enjoying the delights of fine fishing.

Early Surveys in Virginia. P. A. Bruce[4] says that, during the seventeenth century, surveys made in Virginia were very inaccurate on account of the carelessness of surveyors and the defects in their instruments. "It was the custom of the surveyor to adopt the banks of a river or creek as his base. . . . From either end of the base line the surveyor drew a line at right angles, which was carried to the length of a statute mile as a rule. At the terminus of each of these lines he was expected to leave some mark to distinguish the spot. This generally consisted of four blazes in a tree." No wonder that disputes arose over the limits of these surveys. "In the seventeenth century the surveyor's compass, like that of the mariner, was not graduated, and was, therefore, untrustworthy for a survey in which the nicest accuracy in measurement was required. The subdivisions of the surveyor's compass did not extend further than two degrees and forty-nine minutes (that is $\frac{1}{32}$ of 90°), and in consequence the bearing of all objects must have been shifted no less than one degree and twenty-five minutes from their real position. This important difference was not recorded in the survey."

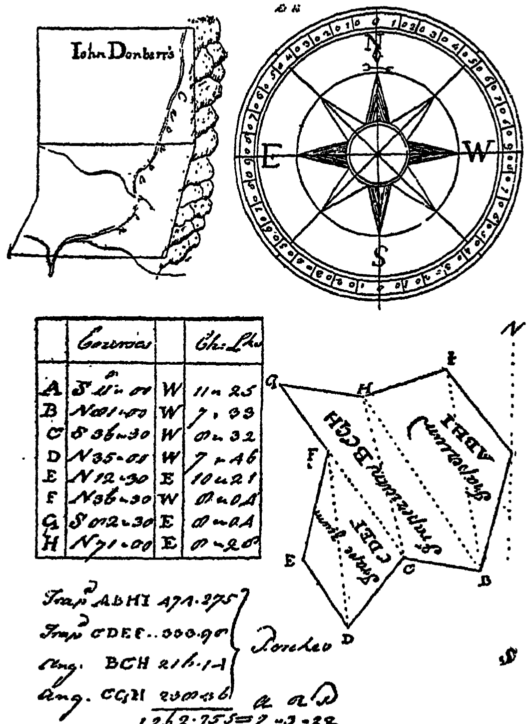

Fig. 19. Drawings made by George Washington at the age of 16.

It is of interest to Americans that George Washington, when a boy of sixteen, studied mathematics and surveying. Fig. 19 is a facsimile of a drawing made by his hand, exhibiting the compass, the graduation of the circle, etc.[5] In his drawing we observe that the graduation in degrees had taken the place of the subdivisions according to the 32 points of the Mariner's compass which we found in instruments used in Virginia in the previous century. The inventory[6] of Washington's library contained a work on surveying, namely William Leybourn's "Compleat Surveyor:

containing the whole art of Surveying of land by the plain table, circumferentor, theodolite, peractor, and other instruments. London, 1679."

Bienville in Ohio. An unusual mode of marking surveys is instanced by Washington Irving.[7] He tells us that Celerou de Bienville attempted to establish reasonably permanent landmarks by nailing leaden plates to trees and burying others in the earth at the confluence of the Ohio and its tributaries. These plates bore inscriptions purporting that all the lands on both sides of the rivers to their sources appertained to the Crown of France. One of these plates, bearing the date, Aug. 16, 1749, was found much later at the confluence of the Muskingum with the Ohio.

New York Boundaries. Some details have been handed down relating to the instruments used on the boundary of New York. On August 12, 1766, Governor Sir Henry Moore wrote to the Lords of Trade on the determination of the line between New York and Canada.[8] "I . . . shall not trust to my own skill and judgment, but shall take with me the mathematical professor (this seems to have been Robert Harpur) of the College here [i. e. King's College, now Columbia University], and a very fine instrument now in his possesion, and every observation made, will be in the presence of several Gentlemen of Fortune in the Province, who have promised to attend me in this troublesome expedition."

The account of a later survey gives some information on the instruments used. Surveying with compasses was subject to two important errors: One arising from the deflection of the magnetic needle due to iron ore deposits in the lands to be surveyed; the other due to irregularities in the behavior of the needle resulting from infinitesimal particles of iron accidentally embodied in the instrument during the process of manufacture. The latter defect could be detected by comparing the readings of different instru-

ments at one and the same locality and for different parts of the graduated circle. The troubles experienced by surveyors are illustrated by the following report made by W. Nicoll and G. Brancker on November 5, 1773, on their survey of the boundary line between New York and Massachusetts Bay:[9]

"The surveying instruments were then produced, and on comparing them it was found that the Massachusetts Instrument would run the Line considerably more East than our Instrument. . . . The Massachusetts Gentlemen chose their Instrument should be used, we consented, and that afternoon went about 25 Chains; the next Morning they chose to go back to Oblong Corner and examine the Course that had been run, in doing which we discovered a Defect in their Instrument, on which they agreed that ours should be used in preference to it, the Survey went on with our Instrument for about six Miles, but finding the Needle frequently affected by Minerals, the Massachusetts Gentlemen expressed a Doubt whether we had continued on the true Course."

Surveyor's compasses were among the instruments made by David Rittenhouse in Philadelphia.[10] He introduced improvements particularly in the structure of the needle. In 1828 a writer in *Silliman's Journal,* (Vol. 14, p. 269) informs us that the U. S. Government, with the design to promote accuracy, at one time directed "that no compasses be used in its surveys, but such as have Rittenhouse's improvements."

Usually, during colonial times, surveyors were licensed by the Surveyor-general of the province. Thus, Thomas Smith appeared in 1769 at the Land Office in Philadelphia and gave bond to the amount of two hundred pounds "for faithful performance of duty." He received detailed instructions to be followed by him as a surveyor.[11]

Early boundaries between Pennsylvania and Maryland. Great interest centers in the surveys and boundaries of Pennsylvania and her neighbors. A century long boundary dispute between Pennsylvania and Maryland gave rise to several surveys. Until the time of the Revolution, Delaware was under the authority of the governor of Pennsylvania. In 1682 William Penn received from the Duke of York the town of Newcastle (Delaware), with a territory twelve miles around it, (See Fig. 20.) extending southward upon the river Delaware to "Cape Henlopen." Lord Baltimore in Maryland protested, the King was appealed to, and a Committee of arbitration appointed. That Committee directed the peninsula north of a line running west from "Cape Henlopen" (Fenwick Island) to be divided between the parties. The division was made so that Penn obtained approximately what is now the state of Delaware.[12] The circular arc of twelve miles radius with its center at Newcastle, as seen on our modern maps, caused surveyors much trouble.

The degrees of accuracy reached in state boundary surveys of the seventeenth century are of some interest. In 1682 boundary commissioners representing Pennsylvania and Maryland were to meet. The Maryland commissioners, while waiting a week at Bohemia Manor for the arrival of those from Pennsylvania, took observations showing the latitude of that place to be 39° 45′ (which is really 39° 30′)[13]. This discrepancy of 15 minutes of arc involves a distance north and south of about 17 miles. A large sextant belonging to Colonel Morris of New York was shipped to New Castle, Delaware; the Maryland commissioners went to New Castle and, using the Morris instrument, found the latitude of New Castle to be 39° and 40 odd minutes (it is 39° 40′). Later, the latitude of Upland (the present Chester) was determined by the use of the Morris sextant to be 39° 47′ 5″ (the latitude of the place is 39° 51′).[14]

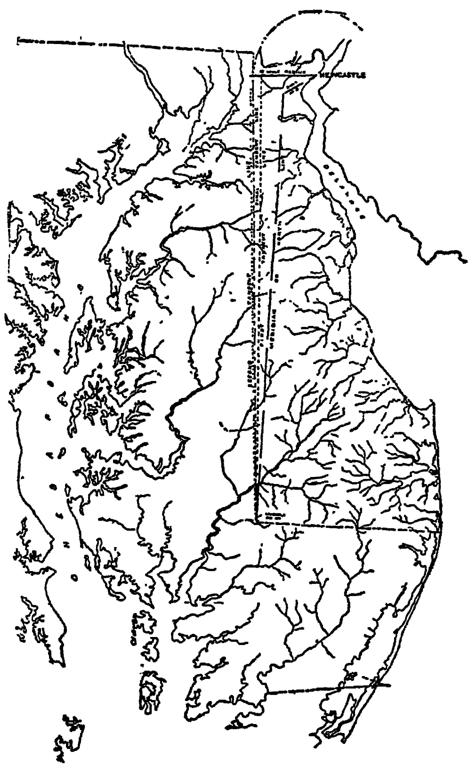

Fig. 20. *Map* showing the lines run to determine the tangent line and the tangent point. Notice the arc having Newcastle as its center; notice the transpensinsula line in the south drawn westward to the Middle Point, also the meridian line and the first, second and final "tangent line." From the *Report on the Resurvey of the Maryland-Pennsylvania Boundary Part of the Mason and Dixon Line,* 1909, p.

It would seem that this instrument was one of the best that was then available. A discrepancy of 3′ 55″ involves about four and a half miles.

About this time (1682) Col. George Talbot, representing Maryland, ran a line from the mouth of Octoraro Creek on the Susquehanna River eastward to Naaman's creek

on the Delaware. "Although this line was apparently run in a careless way, without the use of refined methods or good instruments, and was marked by no monuments more permanent than blazed trees, it was destined to be of critical value in the contest conducted by coming generations."[15] It was the first boundary line actually run between Maryland and Pennsylvania.

That there are cases on record of attempts at great accuracy in seventeenth century surveys is illustrated by the fact that James Conoway, Alex. Dennett, Robert Jones, on March 2, 1683, took latitude observations on "Palmer's Island (now called Garrett Island), situated in the mouth of the Susquehanna River, with a "Sextant of about tenn foote Semi-diameter and (to the best of our Art and Skill) to lie at 39° 44′."[16] This sextant was probably constructed by the surveyors themselves.

A half century later, as the country came to be more widely settled, boundary disputes between Maryland and Pennsylvania became more acute. No satisfactory survey of the circle at Newcastle had been made. (See Fig. 20.) In 1739 the question was discussed as to whether the miles should be measured horizontally or superficially. The same question arose in 1750. As to the process of locating the circle, the surveyors representing Pennsylvania in 1750 held that the circle be determined by a series of chords subtending each one degree of arc. The surveyors from Maryland wanted to run radii from the center of town which it had been agreed should be at the Courthouse. At this time the mode of procedure was left unsettled. No serious survey of the circle was made until 1763, when David Rittenhouse was entrusted with the task of locating the circular arc. This was the earliest of his several public services in the fixing of boundaries. With instruments of his own manufacture he laid out the circle topographically and went "through a number of tedious and intricate calculations."

His work proved to be so satisfactory that he was tendered extra compensation. When in 1768 Mason and Dixon completed their famous line, they accepted the Rittenhouse circle without change.

Further west, in 1739-40, a temporary *ex parte* line was drawn by commissioners of Pennsylvania which marked the boundary line betwen part of the provinces of Pennsylvania and Maryland. It became the accepted boundary between that part of Maryland and Pennsylvania, until Mason and Dixon's survey in 1763-68.

After many attempts to reach a settlement of the boundary in the region which is now the southern boundary of Delaware, the commissioners of Pennsylvania and Maryland met at New Castle in August, 1760, and agreed upon a plan which, as a preliminary step, required the determination of the "Middle Point" of the transpeninsular line run westward from Fenwick's Island and the survey, from that point, of a meridian line extending northward until it intersected a line run from the center of New Castle in such a way as to avoid the Delaware River. See Fig. 20. When the lengths of these lines and their angle of intersection were determined by the surveyors, the commissioners proposed to use these data for the computation of the true course of the "Tangent Line" starting from the "Middle Point" just referred to. It was agreed that this line be made tangent to a circular arc opening southward, being drawn with New Castle as its center and with a radius of twelve miles. This arc was to mark the northern bounds of the territory granted to William Penn. This problem of drawing a tangent line looked easy on paper, but as a problem in practical surveying to be executed on a large scale it was as difficult as it was unique. It was agreed, that the point of tangency should be determined by the survey of a radius extending from New Castle a horizontal distance of twelve miles in the particular direction deter-

mined from the data of the preliminary survey. As we have seen, Rittenhouse layed out the circular arc in 1763.

In a survey carried on in December, 1760, the "Middle Point" of the transpeninsular line was determined and marked with a white oak post.[17] The surveyors proceeded, according to instructions, to run a meridian line from this point northward until it should intersect with the line from New Castle, which they were also authorized to run. They ran the meridian line six miles northward and then stopped work until the following March (1761), when they resumed the survey and, in June, reached the 25th mile post. They suspended work there, because the star Alioth (the bright star ε Ursae Majoris), by which they had been taking meridian directions, could no longer be used, as it passed the meridian in the day time.[18] Returning to the place where the last meridian observation had been taken, they began using another star. They ran the line about 80 miles north from the "Middle Point," until they intersected the line, drawn straight westward from Newcastle, at a distance of over seven miles from Newcastle. The two lines made an angle of 113° 36′. A true tangent line should be at a distance of 12 miles and make an angle of 90° with the radial line. It was estimated from the data obtained that the tangent line would make an angle of 3° 32′ 5″ westerly of the meridian line previously surveyed, and that the radius from Newcastle to the tangent point should be 19° 3′ 5″ north of the southwesterly intersection line that had been run. The surveyors ran the radius of twelve miles (horizontal measure) on the course indicated and set up a post at the end of the line, marked M/XII. In the spring of 1762 the surveyors repaired south to the "Middle Point" and ran a "Tangent Line" making the angle 3° 32′ 5″ westerly from the meridian line. The angle of intersection with the radius should have have been 90°, but exceeded this amount by 26′; moreover, the "Tangent

Line" passed nearly half a mile west of the post M/XII. The errors were too great to satisfy the commissioners of the provinces. A second "Tangent Line" proved to be more accurate and, perhaps, might have been accepted, if the commissioners had not received word from England that two mathematicians, astronomers and surveyors, Charles Mason and Jeremiah Dixon, were coming over to assist in running the lines.[19]

The Mason and Dixon Boundary Surveys. Mason and Dixon were employed by the proprietors of the two provinces, apparently in a private capacity, on the recommendation of Nevil Maskelyne, the Astronomer Royal, with whom the two men had previously worked. Before this they had been employed in making observations of an eclipse in Africa. Mr. Mason, after some years in Europe at work on astronomical tables, returned to America with his wife and eight children. He died in Philadelphia in 1787. Dixon died in England ten years earlier.[20]

Mason and Dixon were instructed by the commissioners to make certain latitude determinations. Recent study of their work indicates that their determinations of latitude were made much more accurately and carefully than their determinations of distances.

They spent Dec. 19, 1763, to Jan. 4, 1764 in observations on the latitude of the most southern point of the city of Philadelphia, after which they spent two days in reducing their observations and in computation of the latitude, which they made[21] 39° 56′ 29″. The modern value is 39° 56′ 26.6″, a difference of only 2.4″. The latitude of the parallel which was to mark the northern boundary of Maryland was computed by them to be 39° 43′ 19.9″. Here the error is 2.3″, but in the opposite direction to that in Philadelphia, making for the interval between the parallel line and Philadelphia a total discrepancy of 4.7″. The zenith sector which they used "was preserved at Harrisburg until the

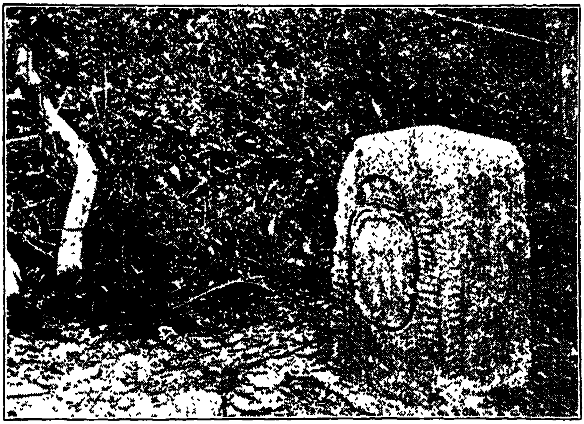

Fig. 21. Original Mason and Dixon Monument (No. 32). Crownstone showing Baltimore Arms, one mile west of Cardiff, reset. (This figure is taken from *Report of the Maryland-Pennsylvania Boundary Part of the Mason and Dixon Line,* 1909, plate LXXX.

Fig. 22. Jeremiah Dixon's Theodolite, now in the possession of the Royal Geographical Society of London.

destruction of the State Capitol. At that time it had been taken apart for cleaning and since that time only a few of the parts have been recovered." A theodolite carried by Mason and Dixon has lately become the possession of the Royal Geographical Society of London.[22] See Fig. 22. It was used by them in some of the minor operations. It had no telescope, but only two plain sights. It was made By George Adams, a London instrument maker of the middle of the eighteenth century.

On June 25, 1764, Mason and Dixon went to the "Middle Point" on the transpeninsular line and began running the "Tangent Line" which had been attempted twice before. (See Fig. 20.) After making several checks and corrections on their own determinations, they obtained on November 10 what they took to be the true "Tangent Line." Instead of wooden posts, they used stones as land marks. (See Fig. 21.) Some years later the stone at the "Middle Point" was dug up by persons looking for Captain Kidd's treasure.[23]

In April, 1765, Mason and Dixon began the survey of the western line which has since been associated with their names. They proceeded westward about 230 miles when they were stopped by the Indians.[24] Their work for the provinces ended in September, 1768. The surveys cost the proprietors fully $75,000. How much more was spent in lawyers' fees, the gathering of testimony and the prosecution of trespassers will never be known.[25]

The Pennsylvania-Virginia boundary. In 1782 Alexander McClean made an *ex parte* extension of the Mason-Dixon line twenty-three miles westward and thence proceeded northward. This served as a temporary boundary. Later, Pennsylvania and Virginia appointed commissioners to extend the Mason-Dixon line a distance of five degrees (as near as possible) west from the Delaware. Pennsylvania appointed John Ewing, David Rittenhouse, John Lukens,

and Thomas Hutchins; Virginia appointed James Madison, Robert Andrews, John Page and Andrew Ellicott. Of these men Ewing, Rittenhouse and Ellicott were well-known American surveyors and astronomers; John Lukens was surveyor-general of Pennsylvania, Hutchins was an experienced topographer, Madison was president of William and Mary College and later first bishop of Virginia, Andrews was professor at William and Mary College, Page was a friend of Thomas Jefferson and later governor of Virginia. In April, 1784, David Rittenhouse was busily engaged in making the necessary instruments for the survey. In June he with Lukens, Page and Andrews, erected a temporary observatory at Wilmington, Delaware, where they made a series of sixty observations of the eclipses of the moons of Jupiter before their departure into the western wilderness, where Mason and Dixon had been stopped by the Indians seventeen years previously. Page and Lukens were unable to endure the hardships of the six-month's travel through the wilderness, and returned home.[26] A report of the survey was signed November 18, 1784, by Robert Andrews, John Ewing, Andrew Ellicott, David Rittenhouse, and Thomas Hutchins.[27]

In 1785 the running of a due north line from the western terminus was completed. As previously stated the commissioners had made sixty different observations at the eastern end of the Mason-Dixon line; they made between forty and fifty on the western end.

Pennsylvania-New York boundary. In the latter part of the eighteenth century, David Rittenhouse was employed by the state governments in several important geodetic operations. As previously stated he was named one of the commissioners for adjusting the territorial dispute between Pennsylvania and Virginia, in 1786 he was called upon to determine the boundary between Pennsylvania and New York, and in the following year the boundary between

New York and Massachusetts. Andrew Ellicott described some of these operations:

"The state of Pennsylvania[28] is bounded on the north by the 42° of north latitude. This line extends from a point on the Delaware, (which was fixed by Dr. Rittenhouse and Captain Holland in the year 1774,) and extends west to Lake Erie: it was completed in the years 1786, and 1787.

"My associates in tracing[29] the north boundary of Pennsylvania were Dr. Rittenhouse, James Clinton, and Simeon De Wit, in the year 1786. The first of those gentlemen left us in the beginning of September. The year following my associates were Andrew Porter, Abraham Hardenberg, and William Morris." In further appreciation of Rittenhouse, and indication of instruments used, Ellicott stated in another article:[30]

"The zenith distances were taken by the sector which was used on the northern boundary of this state (Pennsylvania) and was made by our own countryman, Mr. Rittenhouse, and graduated by a method of his own." In fact, the New York representatives relied entirely upon the Pennsylvanians for the supply of instruments; there was no other sector available for the purpose. The surveys carried on by these men do their memory great credit. Both Rittenhouse and Andrew Ellicott constructed their own instruments.[31]

About a quarter of a century later, Ellicott was active in a survey to settle a boundary dispute between the United States and Canada, in which F. R. Hassler participated.

U. S. Government Surveys of Public Lands. In 1785 the Congress of the Federated States provided for the survey of its territory north and west of the Ohio River. Thomas Hutchins, then well-known as a writer on topography, was appointed geographer of the Federated States. As we have seen, he had served as a commissioner on boundary surveys, along with John Ewing, John Lukens

and David Rittenhouse. With the aid of thirteen assistants Hutchins started in 1785 from the south-west corner of Pennsylvania and laid off a line due north to a point on the north bend of the Ohio River. From there they started a line westward, but proceeded only forty-two miles, when they were frightened away by the Indians.[32] Hutchins died in 1789. For several years no substantial progress in the government surveys appears to have been made. An act of Congress, approved May 18, 1796, provided for the appointment of a surveyor-general and directed the survey mouth of the Kentucky River. After the opening of the new century, two men of ability gave their services to the government of the United States—Jared Mansfield and Josiah Meigs. Mansfield, as a boy, had made a bad beginning at Yale College, culminating in his expulsion when he was in his senior year. Later, as his character developed, he recovered the esteem of the College circle and in 1787 was given the degree of Master of Arts and in 1825 the honorary degree of L L. D.[33] As previously noted, he published in New Haven, a volume of *Essays, Mathematical and Physical.* and attracted thereby the attention of President Jefferson who, in 1803 appointed him Surveyor-General of the Northwestern Territory. His son Edward D. Mansfield explains further: "He was not appointed for the purpose of practical surveys, as they are now carried on, but for the purpose of determining astronomically certain lines of of the lands north-west of the Ohio River and above the latitude, and the principal meridians on which the surveys were thereafter to proceed, and in fact, have ever since proceeded. . . . He was directed, if possible, to determine the southern extremity of Lake Michigan, the western extremity of Lake Erie, the confluence of the Ohio with the Mississippi, and the western boundary of the Connecticut Reserve. For this purpose astronomical instruments were necessary. Mr. Jefferson, who was a warm friend of science,

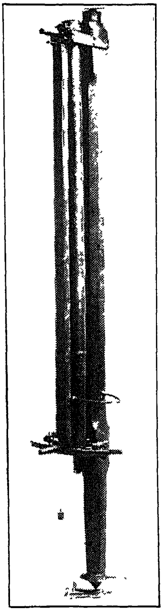

Fig. 23

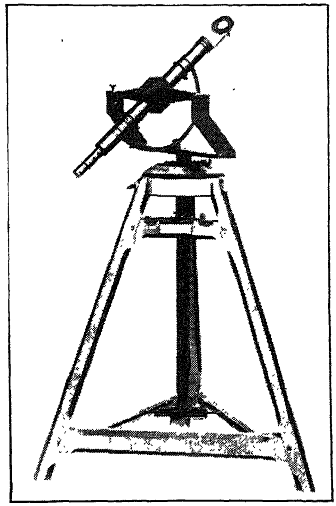

Fig. 24

Fig. 23. Large Zenith Sector used by Capt. Andrew Ellicott. Now in the United States National Museum, Washington, D. C.

Fig. 24. (On the right) Transit and Equal Altitude Instrument, made by Capt. Andrew Ellicott about 1789. Now in the United States National Museum, Washington, D. C.

directed the purchase out of the *contingent fund* of the President of a transit instrument, a telescope, an astronomical clock, and a sextant. They arrived in Cincinnati in 1805 or 6, were placed in the house of the Surveyor-General, and constituted, as I believe, the first real observatory erected west of the Alleghany Mountains. There, during a series of years, numerous and interesting astronomical observations were made. The orbit of the comet of 1807 was calculated and recorded in the transactions of the Connecticut Academy of Arts and Science; eclipses of various kinds observed, the longitude determined, and all other observations made which the nature of the instruments and the early settlement and rude state of the country would allow."[34] When, in 1812, Jared Mansfield was appointed to the chair of natural and experimental philosophy at West Point, a portion of these instruments were removed from Cincinnati to West Point. Mansfield was the first to run the meridian lines on which is based the system of public surveys.

Mr. J. Meigs of the General Land Office, in 1819, described the surveys of Public Lands as follows:[35]

"In May, 1785, Congress adopted the plan of laying out the public lands in townships, *six miles squares*. . . . The *east* and *west* boundaries of townships being meridians, it is evident that their approximation, though scarcely sensible in a space of *six* miles, would, if not corrected, throw into the form of a *parallelogram* the township which, by law, was to be a *square*. To obviate this, the deputy surveyors are instructed to form a new *base* or *parallel to the equator*, at every 24 or 30 miles. The corners of each section and quarter section are defined by marks on at least *two trees*, whose *species, diameter, distance* and *bearing*, by the compass, are entered on the *field notes*. The *magnetic* variation at the time of the survey is also noted for each township. Each deputy surveyor deposites his field notes

in the office of the surveyor general within whose district the land is . . . This wise system takes away all temptation to incur the curse pronounced by *Moses* on him '*who removeth his neighbor's land mark.*' . . . Very few disputes as to *limit* or *boundary* can arise. It is a subject of regret that the spirit of this system was not, at an early day, adopted by Kentucky, Tennessee, and several other states. It has been said, that, probably, as much money is annually expended in those states in *land-title litigation* as would defray their taxes for the support of the severest war. . . . To furnish the materials for an easy, certain, and precise definition, *five principal meridians* have already been designated and marked. The first commences at the confluence of the *Great Miami* and the *Ohio*. This meridian extended to the north boundary of the United States, is 450 miles in length. The *second principal meridian* commences on the *west* branch, at a point five miles south west of the confluence of the *Little Blue River* with the Ohio;—

"The *third principal meridian* commences at the confluence of the Ohio and Mississippi, . . . the *fourth principal meridian* was run for the purpose of surveys for military bounties for the soldiers in the late war. It commences at the confluence of the rivers *Illinois* and *Mississippi*. . . . The *fifth principal meridan* begins at the confluence of the Arkansas and Mississippi rivers. . . . So wise, beautiful and perfect a system was never before adopted by any government or nation on earth. It is the 'eorte diaseise' the divided feast of Homer. The government, with a temper and spirit truly *parental,* has divided, for the *children* of the republic, that patrimony in which they all have a right and an interest."[36]

Josiah Meigs, whose article we have been quoting, had a varied career. At one time he was tutor in mathematics, natural philosophy and astronomy at Yale, later he practiced law in Bermuda. Then he returned to Yale and in 1801

became president of the University of Georgia. In 1812 he was appointed Surveyor-general of the United States and in 1814 commissioner of the general land office at Washington, in which capacity he served until his death in 1822. Before 1818 the United States had already established twenty land offices. Meigs advised that meteorological observations be taken at each place.[37]

The City of Washington. Major L'Enfant,[38] a French engineer who had served in the Continental army and to whom George Washington had become greatly attached, was first engaged on the survey of the District of Columbia. Washington and L'Enfant frequently rode over the site of the city together. Under the direction of Major L'Enfant, the laying out of the city was begun, but he became thoroughly discouraged because of the obstacles placed in his way by unsympathetic commissioners. After his resignation, the plans that Washington and he had decided upon were developed and carried out, as far as they could be, by Andrew Ellicott.[39]

Boundary between the United States and the Spanish possessions. In 1783, Florida was restored to Spain, after having been a possession of Great Britain for twenty years. In 1795 a treaty between the United States and Spain, known as the Pinckney-Godoy Treaty, defined an exact boundary between the possessions of the two countries, which scientists of the two countries fixed during the years 1796-1800. The new boundary line started at the Mississippi river, a little north of Baton Rouge and thence proceeded eastward. That survey is noteworthy because some instruments of highly improved quality were employed. The most noted instrument makers of the close of the eighteenth century were Jesse Ramsden (1735-1800) and Edward Troughton (1753-1835), of London. Before 1789 Ramsden had constructed nearly a thousand sextants. The demand for his instruments from all parts of Europe was greater

than could be met by the constant labor of sixty workmen. A few of his instruments found their way to America. Thus, a Ramsden quadrant was used[40] at New Port, Rhode Island, October 27, 1780. Another one of seven inch radius, the vernier dividing to 20″, was used in the determination of the boundary between the United States and the Spanish possessions.[41]

But the large and delicate theodolites on which his fame chiefly rests never reached America. They could not be procured in the open market and were manufactured only on special order. One of these, four feet in diameter, carrying a telescope of three feet focal length, was completed in 1787 for the use of General William Roy, in his trigonometric survey of England.[42] No instrument of the kind that had been made previously would bear comparison with it. Another one was completed by Ramsden in 1796 for the Government of the Canton of Bern in Switzerland. This instrument is of special interest to Americans, because it was used in Bern by F. R. Hassler, who later migrated to America and became the first superintendent of the United States Coast Survey. R. Wolf[43] speaks critically of this masterpiece of Ramsden: "This instrument was much too unwieldy to be used in a mountain region, and moreover, its construction came at a time which was rapidly followed by a complete transformation of geodetic instruments, so that it was antiquated in a few years. This and not its excellence, was the reason (as was often boasted) that only three such instruments were ever constructed."

It was the ambition of Edward Troughton to equal and surpass Ramsden in the design and precision of instruments. Before the beginning of the nineteenth century, one of Troughton's instruments, an "astronomical circle", was used by the Spanish engineers who worked with those of the United States in determining the boundary described above.[44]

Instruments in America at the Opening of the Nineteenth Century. The fact alluded to above does not invalidate the general statement that the geodetic and astronomical instruments with which scientists in America, North and South, had worked and acquired familiarity, at the beginning of the nineteenth century, were instruments of the older type. New types of repeating instruments like those of Tobias Mayer and Borda, had not been used here. The special designs of highly developed instruments which went out, the pride of the achievements of Ramsden, Borda and Troughton, were not used in America before 1816. The geodesists of England and Switzerland had acquired familiarity with the best product of the genius of Ramsden at a time when surveyors of the United States were still working with older instruments. This failure of our people to keep in intimate touch with scientific movements in England, is the less surprising when the ill-feeling generated during the war of the Revolution is brought into consideration. The free and easy intercourse between the two countries ceased. No longer did Englishmen send some of their best scientific instruments to their kinsmen in America, as was done in 1769 for observations of the transit of Venus. After the Revolution, seldom did observers in the United States send their data to England for publication in the Philosophical Transactions of London. Now the two countries represented independent intellectual units with few channels of inter-communication. The movements for independence in Mexico and New Granada (Colombia) produced similar results in the relations of these countries toward Spain. This increased isolaton tended, for some years, to retard progress of Amercan science. It was, therefore, a fortunate circumstance that a young man, F. R. Hassler, arrived from Europe who had had training as a geodesist, who had experience in the use of the modern instruments in astronomy and surveying, and was familiar with the

most up-to-date processes in practical geodesy. He had used in surveys one of the great instruments from the workshop of Ramsden, and for years had been the proud professor of a repeating reflecting circle of Borda; it was fortunate that Hassler was eventually entrusted with the organization of the United States Coast and Geodetic Survey.

Maritime Surveys.[45] Important maritime surveys of America were carried on in the eighteenth century by four Englishmen, Joseph Frederick Walsh Desbarres, Samuel Holland, George Gould and George Vancouver. Desbarres was a military engineer, served with Wolf at Quebec, was engaged from 1763 to 1773 in surveying the coast of Nova Scotia,[46] and later devoted sixteen years to the survey of the North American Coast and the preparation of charts thereof. In 1774 he published the "Atlantic Neptune,"[47] which was the most splendid collection of charts, plans and views published at that time. It was executed at the expense of the British Government for the use of the British Navy.

Samuel Holland published in 1776 at London Charts of the Coasts and Harbors of New England, that were surveyed under his direction.

George Gould published in 1790 and 1796 at London accounts of surveys of the Florida Coast.[48] According to Andrew Ellicott, Gould's maritime surveys were of unsurpassed excellence at that time. As stated in the extracts from Gould's journal that are printed in the introduction to his book of 1790, he served as a volunteer in defence of Pensacola during the siege and capture of that place in 1781 by the Spanish and French Navy and by the Spanish, French and American troops.

Of George Vancouver, Davidson[49] says: "The only available chart of the N. W. Coast of America was that of George Vancouver who executed a very remarkable survey reconnaissance of the N. W. Coast of America from latitude 30° along the continental shore, in 1792, 1793, 1794, and published by the [British] government in 1798."

1. Charles de la Roncière, *La carte de Christophe Colomb*: The *Map of Christopher Columbus,* Paris, 1924. See discussion in *Isis,* Vol. 8, 1926, p. 168-172.
2. Benjamin Garcia Aparicio *La Carte de la République Argentine,* Buenos-Aires, 1913, p. 5.
3. Miguel Barquero, *Algunos Trabajos de los Misioneros Jesuitas en la Cartografia Colonial Española,* Barcelona, 1914, p. 35.
4. P. A. Bruce, *Economic History of Virginia in the Seventeenth Century,* New York, 1896, Vol. I, p. 537-539.
5. Jared Sparks, *Writings of George Washington,* Vol. 1, New York, 1852, p. 8.
6. A. P. C. Griffin, *Catalogue of the Washington Collection in the Boston Athenaeum,* 1897, p. 550.
7. W. Irving, *Life of Washington,* New York [1855], Vol. I, p. 45.
8. State of New York. *Reports of the Regents of the University on the Boundaries of the State of New York.* Prepared by Daniel J. Pratt,, Vol. II, Albany, 1884, p. 1.
9. Loc. cit., Vol. II, 1884, p. 178.
10. *Transactions of the American Philosophical Society,* Vol. V, Philadelphia, p. 206.
11. These instructions are printed in full in Burton Alva Konkle's *Life and Times of Thomas Smith,* 1745-1809. Philadelphia, 1904, p. 32-35.
12. John H. B. Latrobe, *The History of Mason and Dixon's Line,* Philadelphia, 1855, p. 20.
13. *Report on the Resurvey of the Maryland-Pennsylvania Boundary Part of the Mason and Dixon Line.* Published by the Authority of an act of Assembly of Pennsylvania, approved May 13, 1909, p. 128.
14. Loc. cit., p. 129.
15. Loc. cit., p. 137.
16. Loc. cit., p. 246.
17. Loc. cit., p. 181.
18. Loc. cit., p. 182.
19. Loc. cit., p. 184.
20. Loc. cit., p. 185.
21. Loc. cit., p. 40, 41.
22. *The Geographical Journal,* London, Vol. 47, 1916, p. 1-3; Vol. 48, 1916, p. 337.
23. Loc. cit., p. 352.
24. *Report on the Resurvey of the Mason and Dixon Line,* 1909, p. 189.
25. Loc. cit., p. 190.
26. S. W. Pennypacker in *Harper's New Monthly Magazine,* Vol. 64, 1882, p. 845.
27. *Report on the Resurvey of the Maryland-Pennsylvania Boundary Part of the Mason and Dixon Line,* 1909, p. 366.
28. "The Theory and Method of Calculating the Aberration of the Stars, the Nutation of the Earth's Axis, and the Semiannual Equation" in a letter from Mr. Andrew Ellicott, to Robert Patterson in the *Transactions of the American Philosophical Society,* Vol. IV, Philadelphia, 1799, p. 39-40.
29. Andrew Ellicott, loc. cit., p. 48.

30. Accurate determination of the right ascension and declination of *B*. Bootes, and the Pole Star: in a Letter from Mr. Andrew Ellicott to Mr. R. Patterson, in *Transactions of the American Philosophical Society,* Volume III, page 116, Philadelphia, 1793.

31. C. Van Cortlandt Mathews, *Andrew Ellicott, His Life and Letters,* New York, 1908, p. 69.

32. W. E. Johnson, *Mathematical Geography,* 1907, p. 228, 229.

For a detailed statement of the legislation providing for the survey of the Northwestern Territory see Edward D. Mansfield, *American Education,* New York, 1851, p. 155-161, and also *Manual of Instructions for the Survey of the Public Lands of the United States* (Advance Sheets), Washington, 1919. (Department of the Interior).

33. F. B. Dexter, *Biographical Sketches of the Graduates of Yale University,* Vol. III, 1903, p. 691-694.

34. Edward D. Mansfield, op. cit., p. 158-160.

35. Niles' *Weekly Register,* Vol. XVI, 1819, p. 362, 363.

36. For further details on the survey of Public Lands, see *Niles' Weekly Register,* Vol. 12, 1817, p. 97, 406.

37. *Niles Weekly Register,* Vol. 12, p. 167.

38. For details relating to L'Enfant's services, see *Records of the Columbia Historical Society,* Washington, D. C., Vol. 2, 1889, p. 26-118.

39. Andrew Ellicott, *Trans. Am. Phil. Soc.,* Philadelphia, Vol. 4, 1799, p. 49-51. For biographical details consult C. Van Cortlandt Mathews, *Andrew Ellicott, His Life and Letters,,* New York, 1908.

40. Memoirs American Academy of Arts and Sciences, Vol. I, Boston, 153.

41. *Transactions of the Am. Phil. Soc.,* Vol. V, Philadelphia, p. 205. For a list of instruments used in 1796-1800 by Andrew Ellicott in fixing the boundary line between the United States and the Spanish possessions in Florida, as determined by the Pinckney-Godoy Treaty of Oct. 7, 1795, see also the *Journal of Andrew Ellicott,* Philadelphia, 1803, Appendix, p. 44.

42. General Roy's description of this instrument is given in the *Transactions of the Royal Society* (London) for the year 1790.

43. R. Wolf, *Biographien zur Kulturgeschichte der Schweiz,* Zweiter Cyclus, p. 322, 323.

44. *Transactions of the Am. Phil. Soc.,* Vol. 5, Philadelphia, 1802, p. 208.

45. Consult Justin Winsor, *Narrative and Critical History of America* for early maps: In Vol. 1, 1882, p. 37-62 are "The earliest Maps of Massachusetts Bay and Boston Harbor;" in Vol. II, p. 93-128 are "The earliest Maps of the Spanish and Portuguese Discoveries" and on p. 217-230 "The early cartography of the Gulf of Mexico and Adjacent Parts:" in Vol. IV are "Maps of the Eastern Coast of North America" and "Cartography of the North East Coast;" in Vol. V "Cartography of Louisiana."

46. *The Sea Coast of Nova Scotia,* by Joseph F. W. Des Barres, Esq., London, 1777.

47. *The Atlantic Neptune published for the Use of the Royal Navy of Great Britain.* By Joseph F. W. Des Barres, Esq., under the

Directions of the R. H. Lords Commissioners of the Admiralty. London, 1777. 2 vols. Atlas, folio 146 maps.

48. *An Account of the Surveys of Florida, etc., with Directions for Sailing from Jamaica or the West Indies by the West End of Cuba, and through the Gulf of Florida,* by George Gould, London, 1790, p. 27;

Observations on the Florida Kays, Reef, and Gulf, with Directions for Sailing along the Kays, from Jamaica by the Grand Cayman and the West End of Cuba; also, a Description of West Florida. By George Gould, to accompany his Charts. London, 1796, p. 28.

49. George Davidson, *The Alaska Boundary,* San Francisco, 1903, p. 49.

CHAPTER IV

MERIDIAN MEASUREMENTS OF THE EARTH

The shape and size of the earth has always been a problem of intense interest. Assuming the sphericity of the earth, the Greek mathematician Eratosthenes made a remarkably accurate determination of its size. Arabic astronomers and Europeans before the time of Newton made very creditable measurements of its radius. The exact shape of the earth was a more difficult problem. Is the earth flattened at the poles, or is it elongated there? Both views were entertained. On theoretical grounds, Newton held that the earth was flattened at the poles. The older Cassini's early attempt to find the figure of the earth by actual meridian measurement, in France, seemed to indicate an elongation at the poles.

Ecuador Meridian. Just as it was a French scientist who, with comparatively crude instruments, arrived at the conclusion that the earth was elongated at the poles, so it was French scientists who with better instruments and by two independent meridian measurements—one to Lapland, the other in Ecuador (formerly part of Peru)—disproved that claim and demonstrated that the earth is flattened at the poles. The expedition to Lapland was in charge of Maupertuis, the one to South America was conducted by three Frenchmen—Louis Godin, Pierre Bouguer, and Charles Marie de la Condamine—and two Spaniards—Don George Juan and Don Antonia de Ulloa. The Ecuador expedition started in April, 1735, a year before the one to Lapland, but the latter finished its work much earlier than did the

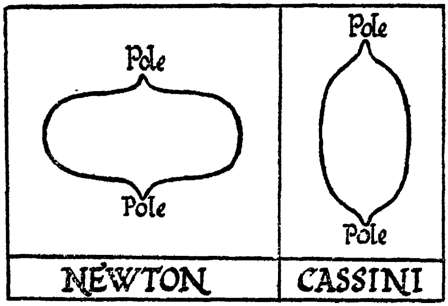

Fig. 25. Old caricature of the two rival theories of the figure of the earth.

former. Both arrived independently at the same conclusion regarding the general shape of the earth; in the words of de la Condamine[1], "we reached Europe, on our return, by seven years too late, to communiate any thing new respecting the figure of the earth." As early as September 27, 1737, Maupertuis wrote to James Bradley, "Thus, Sir, you see the earth is oblate, according to the actual measurements . . . and this flatness appears even more considerable than Sir Isaac Newton thought it." In the words of Voltaire, Maupertuis had "aplati les Poles et les Cassinis." However, the Ecuador measurements were of value. From the Lapland data and the French arc previously measured, the ellipticity of the earth appeared to be $1/178$ but the Ecuador measurements yielded a smaller and, from our present knowledge, more accurate value.[2]

The French academicians on their trip to the equator, landed at Carthagena in the present state of Colombia, where the two Spanish scientists were awaiting their arrival. While on their way, on the western coast of Ecuador, Bouguer and De la Condamine determined the position of the equator, and chisled upon the rocks an inscription to that effect. The plain north east of Quito was chosen as

best suited for base measurements; stations for triangulation were selected on the rugged mountains which hem in the valley in which Quito is situated. Strange to say, the vast height of the mountains was a hindrance in this work, because they were usually enveloped in clouds. In fact, the work was carried on under great difficulties and was very fatiguing. The heat and heavy rains in the valley, the extreme cold, heavy snows and terrific winds of the mountains, the unreliability of local servant help, conspired to delay the completion of the work. The scientists formed themselves into two groups, Juan and Godin in one group began work at the north end; Bouguer, la Condamine and Ulloa in the other group began in the south. Each group checked the computations for their series of triangles by measuring a second base line. The result of the several years work in Ecuador was that the degree of latitude there was 56753 toises. Maupertuis found it to be in Lapland 57437 toises which was greater by 377 toises than the middle degree of France, and greater by 684 toises than the Ecuador degree. Evidently, the degree of latitude was longer near the poles. To understand this result, one must bear in mind that the latitude of a place is determined by instruments adjusted with the aid of a plumb line or level. If the meridian is an ellipse, then it has the geometrical property of an ellipse, namely: two consecutive normal lines forming with each other an angle of one degree intercept a longer arc of the ellipse the nearer both normals are drawn to an end of the minor axis.

La Condamine caused two pyramids to be erected for the purpose of marking for all time the two extremities of the fundamental base line, and thus avoiding the inconveniences experienced in France from want of a similar precaution when Picard's base line was to be verified. Unfortunately there arose a disagreement between la Condamine and the Spanish scientists as to the nature of

the inscription to be placed upon the pyramids. The Spanish declared la Condamine's proposal offensive to His Catholic Majesty.[3] Finally, it was unanimously agreed that the matter should be referred to His Majesty's pleasure. In 1746 an inscription was sent from Spain which is fair to all parties.[4]

As the standard of length in base measurement, the French were supplied with an iron toise (=1.94903659 meters) made at the same time and by the same artist, Langlois, as the toise used in Lapland.[5] In 1758 de la Condamine reported that after the two toises were returned to France it was found that the Lapland toise was a twentieth or a thirtieth of a line shorter than the Ecuador toise. But he believed that originally the two were of the same length, and that the difference noted was due to the shipwreck in the Gulf of Bothnia, when the expedition returned from Lapland.[6]

For angular measurement in Ecuador, quadrants were used. That of the Spaniards had a radius of 24″, that of Godin 21″, that of La Condamine 4 feet. Errors in their graduation were detected, and la Condamine prepared a table of corrections for every degree of his quadrant. Angles were measured by each of the two groups of observers, and a third time by la Condamine. An 18-foot telescope was used by la Condamine; he refers to it in the narrative of his return from Quito.[7]

Bouguer and la Condamine left Quito for France in 1744, Bouguer by way of Carthagena, la Condamine by the Amazon river, so as to be able to make observations of different territories. All sorts of observations were made whenever opportunity presented itself—longitudes, latitudes, temperatures, barometric pressures, pendulum experiments, etc.

In 1866, a traveller[8] describes a marble tablet in a Jesuit church at Quito, containing data found by the French academicians, on the longitude and latitude of the edifice,

its altitude and that of several volcanoes and mountains, its magnetic declination, as well as barometric and astronomical observations, for the year 1736. It was perhaps in recognition of ideals of the French and Spanish astronomers that the Jesuits formed an academy at Quito for the study of astronomy and physics. The school disappeared with the expulsion of the order, about 1767. The meridian measurements and other scientific studies carried on in this region, remote from the recognized centers of civilization of that day, led Humboldt to remark: "It is the volcanoes of Quito which, among all the volcanoes of the new continent, enjoy the most wide-spread renown; for it is to this part of the chain of the Andes, and to these highlands of Quito, that the remembrance of arduous labours for important objects in astronomical, geodetical, optical, and barometrical operations, attaches itself, in connection with the brilliant names of Bouguer and la Condamine. Where intellectual associations prevail, where the multitude of ideas have been awakened which have led simultaneously to the enlargement of several sciences, fame remains long attached to the locality."[9]

Proposed Meridian Measurements on frozen Hudson River. The earliest known plan for meridian measurement in North America was made by J. Alexander in an article that appeared in 1740.[10] He said: "Hudson's River here is frozen over from New York up to Albany, and its course is very straight, almost true north, and the Distance between New York and Albany is above One Hundred and Fifty Miles; New York is in latitude 40° 40′, nearly; so that the Length of above 2 Degrees of Latitude on the Earth might be measured here, with much more exactness than it was possible in England or France, because of the Ascents and Descents, and curved Lines, which, I think, they would continually be obliged to make Allowance for. From all which Difficulties the Mensuration here on the Ice would

be entirely clear." Nothing came of this suggestion. Before this, the base used in Lapland had been measured on the frozen surface of a river, the extremities of the base being on land.

The Mason and Dixon Meridian. While surveying the boundaries of Pennsylvania and Delaware, Mason and Dixon noticed that the boundary between Delaware and Maryland afforded excellent facilities for measuring a long base line. The line was over practically level country. They submitted plans to the Royal Society of London and offered to undertake measurements, if the Society would bear the expense. The Royal Society acted favorably and sent levels, thermometers and a 5-foot brass standard of length.[11] This brass standard was found later to be .0016 of an inch too short; making the length of a degree too large by 10 feet. Instruments already in their possession served to measure the base line. The direction of meridian lines was determined by a sector from transit observations of stars. This sector was six feet in radius, and had a plumb line passing over and bisecting a point at the center of the instrument. It was made by John Bird, of London, as was also their transit instrument.[12] "The levels used were each 20 feet in length, 4 feet in height, made of pine in the form of a rectangle. . . . The plumb line used in setting them level . . . hung in the middle of the levels, being secured in a tube(as protection) from the wind, in the manner of carpenters' levels."[13]

The Mason-Dixon arc is the largest arc ever directly measured. Nevertheless, F. R. Hassler, Nathaniel Bowditch and others were not satisfied with the degree of accuracy that seemed to have been attained. Bowditch says:[14] "It is probable that the degrees in Pennsylvania and Italy, were not measured with all the precautions required by modern observers."

That the dominating motive in the work of Mason and Dixon was the advancement of pure science is evident also from the title of a paper which they contributed to the Philosophical Transactions:[15] "Astronomical observations, made in the Forks of the River Brandiwine in Pennsylvania, for determining the going of a clock sent thither by the Royal Society, in order to find the difference of Gravity between the Royal Observatory at Greenwich and the Place where the clock was set up in Pennsylvania, to which are added, an observation of the end of an eclipse of the Moon, and some immersions of Jupiter's First Satellite observed at the same Place in Pennsylvania." The vexations so frequently experienced in observations are here illustrated by the remark that the "spring at the suspension of the pendulum having been broke, when the ship was wrecked on the Jersey Coast, the pendulum may not be of the same length as formerly."

Distance from Norriton to Philadelphia.[16] On December 26, 1769, N. Maskelyne, then Astronomer Royal of England, wrote to Rev. William Smith in Philadelphia as follows: "I could wish that the difference of meridians of Norriton and Philadelphia could be determined by some measures and bearings, within one fiftieth or one hundredth part of the whole, in order to connect your observations with those made at Philadelphia and the Capes of Delaware, as also to connect your observations of the longitude of Norriton with those made by Messrs. Mason and Dixon, in the course of measuring the degree of latitude." William Smith, the Provost of the College at Philadelphia, undertook these measurements.[17] He measured the distance between Norriton and Philadelphia and found Norriton to be North 79026.3 feet and West 62385.8 feet. He then computed the difference in their latitude and longitude, Norriton being 52″ of time west 13′ 01″.86 of arc north of the State-house square.

1. La Condamine's narrative in *Voyages and Travels* by John Pinkerton, Vol. 14, London, 1813, p. 211.

2. I. Todhunter, *Theories of Attraction and Figure of the Earth,* Vol. 1, London, 1873, p. 101.

3. La Condamine, Narrative of Travels, *Voyages and Travels* by John Pinkerton,, Vol. 14, 1813, p. 212.

4. The inscription is given in Ulloa's narrative of the voyage; see *Voyages and Travels* by John Pinkerton, Vol. 14, p. 648.

5. I. Todhunter, *op. cit.,* Vol. 1, p. 97.

6. I. Todhunter, *op. cit.,* Vol. I, p. 451.

7. La Condamine in *Voyages and Travels* by John Pinkerton, Vol. 14, London,, 1813, p. 223.

8. Don Enrique de Thoron, *Amérique équatoriale,* Paris, 1866, p. 267.

9. Alexander von Humboldt, *Cosmos,* Edition of E. Sabine, Vol. 4, London, 1858, p. 275. Many Notes by Sabine.

10. *Philosophical Transactions,* Vol. 41, 1740, No. 457, p. 383.

11. A. D. Butterfield, *A History of the Determination of the Figure of the Earth from Arc Measurements,* Worcester, Mass., 1906, p. 46-55. Mason and Dixon's "Observations for determining the length of a degree of latitude in the provinces of Maryland and Pennsylvania in North America" were published in the *Philosiphical Transactions of the Royal Society of London,* Vol. 68, p. 274-328.

12. A. D. Butterfield, *op. cit.,* p. 48.

13. Mason and Dixon, *Phil. Trans.,* London, Vol. 68, p. 312.

14. N. Bowditch's edition of Laplace's *Mécanique Céleste,* Vol. 2, Boston, 1832; I. Todhunter, *A History of the Mathematical Theory of Attraction and the Figure of the Earth,* 1873, Vol. 2, p. 207.

15. *Philosophical Transactions* for the year 1768, London, 1769, p. 329.

16. *Trans. Am. Philos. Society,* Vol. I, 2nd Edition, Philadelphia, 1789, p. 113.

17. "Account of Terrestrial Measurements between the Observatories of Norriton and Philadelphia," by William Smith in *Trans. of the Am. Phil. Society,* Vol. I, second edition, Philadelphia, 1789, p. 119, 120.

CHAPTER V

TRANSIT OF VENUS

An extraordinary incentive to the study of astronomy was given by the transits of Venus over the disc of the sun which occurred in 1761 and 1769. From these observations it was hoped that a more accurate determination of the sun's parallax could be made, which would lead to a closer approximation to the distance of the earth from the sun. Before 1761 only one such transit was known to have been observed anywhere. It took place in December, 1639, and was seen by two young astronomers, Jeremiah Horrocks, near Liverpool, and William Crabtree, near Manchester, in England. "Unfortunately, a premature death deprived their country of the two individuals who exhibited such enthusiasm in the cause of science." In 1761 popular interest was not aroused in our Colonies to the same degree that it was in the transit which took place eight years later.

The Transit of 1761. The event was carefully observed in different parts of the world, even though the conditions for observations were not favorable. John Winthrop of Harvard observed it at Newfoundland and described the preparations for it as follows:[1]

"The transit of Venus over the Sun being a very curious and important phenomenon, engaged the attention of America as well as Europe. His Excellency, Francis Bernard, Esq., Governor of the Massachusetts-Bay, a gentleman who seizes every opportunity of advancing the sciences, was desirous to have an observation of it in this quarter of the world; and as Newfoundland was the only

British plantation where one could be had, proposed to the General Assembly at Boston to make provision for that purpose which they readily agreed to do. In consequence whereof, I imbarked on board of a vessel in the service of the government, taking with me for assistants two young gentlemen my pupils; and such astronomical instruments out of the college apparatus as were necessary. There was an excellent clock, Hadley's octant with nonius divisions; a reflecting telescope with wires at half right-angles, for taking differences in right ascension and declination; and a nice reflecting telescope, adjusted by cross levels and having vertical and horizontal wires, for taking correspondent altitudes; or differences of altitudes and azimuths." Not only did Winthrop take the usual time-measurements, but he also "viewed the Sun with great attention in the reflector, both on the 5th and 6th of June, in hopes to find a satellite of Venus, but in vain." One feature of his preparations is of special interest, his use of a *gnomon*. He says: "I . . . secured the clock to a pillar set in the ground under a tent. Near this tent, and within call of the clock, we fixed two other pillars firmly in the ground; one to mount the refracting telescope on, the other which was over eight feet high for a style or gnomon, having at top a plate of lead with a little hole for transmitting the Sun's rays, and we laid an horizontal platform to receive those rays. The platform we kept covered, to defend it from the Sun and weather; and examined its position every time we made use of it, by a very long level. On this we very carefully drew a meridian line, by corresponding altitudes of the Sun, taken both by the reflector and by the Sun's image on the platform. These operations we repeated every fair day and several times in a day. . . . We adjusted the clock with as much exactness as we could have done at home."[2]

We may remark in passing that the gnomon is one of the oldest astronomical instruments. It was employed by the Greeks, but apparently they learned the use of it from the Babylonians and Egyptians.[3] The early instrument was somewhat simpler than the contrivance described by Winthrop; there was no perforated metallic plate on top of the pole. The early gnomon was simply a post, pillar or pyramid, erected upon level ground and with a north and south line drawn through its foot. When at noon the end of the shadow cast by the post fell exactly along the line, the end of the shadow was marked. The height of the gnomon and the length of its shadow being known, the sun's altitude at noon could be determined. A gnomon with a perforated plate came into use certainly as early as the fifteenth century. The post being dispensed with, such gnomon were erected on high buildings, as for example, in the cupola of the dome in Florence, in 1467. Often there was placed vertically below the hole, on the floor or ground a series of horizontal concentric circles. A bright spot of the sun would be cast upon these circles, and would indicate the time of day.

In America the gnomon was employed some; the sun dial, with which the gnomon connects historically, was in common use. Humboldt speaks of the gnomon in appreciative terms: "It is certain that a zealous observer may, with very imperfect means, procure often very satisfactory results. The latitudes obtained by Bouguer in the Rio de la Magdalena in Colombia, with a gnomon from seven to eight feet in height, and employing for a scale pieces of reeds, differ only four or five minutes from what I found fifty-nine years afterwards by means of excellent English sextants."[4]

Returning from this digression to the transit of Venus of 1761, we may add that Winthrop's data yielded for the parallax of the sun the value 8.″25,[5] the more modern figure being 8.″802. We have not seen accounts of other

observations, made in America, of the 1761 transit, but the remarks of William Smith of Philadelphia, which we are about to quote, lead to the inference that other observations were taken. It seems that in the transit of Venus of 1761, observers in Europe worked under a great disadvantage as compared with American observers, for the reason that, during the transit, the sun was seen in Europe so near the horizon as to make accurate observation impossible. William Smith, the Provost of the College of Philadelphia, refers to this circumstance in the following passage:[6]

"As Dr. Halley expresses it, 'Since Venus, like her sex, is exceeding coy, and deigns but in certain ages, to come before the eyes of men, divested of her borrowed dress,' an American, who has the least of the spirit of an astronomer in him, cannot help lamenting for his brother-astronomers in Europe—men of fame and great abilities—that they were condemned, amid horizontal vapors, only to a transient glimpse of this rare phenomenon . . . and that they could not have shared with us some part at least of that luxury gazing, which we enjoyed here." Some European astronomers observed the phenomenon in India and Siberia.

The transit of Venus of 1769 was observed in the City of Mexico by Father José Antonio Alzate, a most zealous student of the natural sciences in New Spain, who sent his observations to Paris, where they appeared in print in 1770. A pamphlet also appeared in Mexico in 1769 under the title *Suplemento a la famosa observacion del transito de Venus,* by Bartolache and Alzate. Humboldt criticized Alzate's time determination as inaccurate, for it yielded a longitude for Mexico far in excess of the true value.[7]

To observe this transit of Venus in 1769, France and Spain sent astronomers to California; England sent one to Hudson's Bay; European expeditions were made to other places.

The French expedition was made under the auspices of the French Academy of Sciences.[8] The observations were taken by Jean Chappe d' Auteroche at the Mission of San Joseph, located at the extreme southern terminus of Lower California. He had observed the transit of Venus of 1761 in Siberia. On Sept. 18, 1768, Chappe left Paris with three assistants and one servant, and with an equipment comprising as the principal instruments a quadrant of three-foot-radius, a transit instrument, an achromatic telescope of ten feet and another of three feet that were both constructed by Dollond in London, and a pendulum clock of Berthoud. Chappe landed at Vera Cruz on March 6, 1769, and at the Mission of San Joseph about two weeks before the time of the transit. He set up his instruments in a large barn, replacing its roof on the south side by an awning, and made careful preparations. On the morning of the eventful day, June 3, Chappe used in his preliminary observations only his left eye, saving his right eye for the important observations that came later. To his great joy, the observations were very successful. His position was one of the most favorable for securing data for the determination of the parallax of the sun. An epidemic was raging in the village; Chappe did all he could to alleviate suffering, but himself contracted the disease. Though ill, he observed the eclipse of the moon on June 18, 1769. Content with the success of his observations, he died on August 1, a victim of the epidemic.

There were two other observers of the transit of Venus in Lower California, the Spanish astronomer Vicente Doz and the Mexican Velazquez, some of whose researches we described earlier. Humboldt interestingly describes the situation as follows: "The observation of the transit of Venus in 1769 occasioned the voyage of M. M. Chappe, Doz and Velazquez, three astronomers, of whom the first was a Frenchman, the second a Spaniard, and the third a

Mexican and, what is more, the pupil of a very intelligent Indian of the village of Xaltocan. However, before the arrival of these astronomers in California, the true latitudes of Cape San Lucas and the mission of St. Rosa had already been found by Don Miguel Costanzo, at present (about 1803) general of brigade and head of the corps of engineers. This respectable officer, who displays the greatest zeal for the geography of the country, found latitudes by gnomon and English octants of a very perfect construction."[9] Humboldt says further that Velazquez "constructed a small observatory in the village of St. Anne, where he observed by himself the transit of Venus, communicating the result of his observation to M. Chappe and Don Vicente Doz. This result was published by M. de Cassini."[10]

Another French transit of Venus expedition was that of A. W. Pingré and De Fleurieu, to the island of St. Domingo where at Cape Francis, they observed a peculiar optical phenomenon reported by several other observers (Rittenhouse, for instance), namely, that when the planet had a little more than half entered upon the disc of the sun, the whole circumference of the planet was seen with a narrow border of light which illuminated that part of the circumference which was off the sun. This border disappeared two or three minutes before the internal contact.[11]

The expedition to Hudson's Bay was under the auspices of the Royal Society of London, which sent the astronomers William Wales and Joseph Dymond to the Prince of Wales fort on the northwest coast of Hudson's Bay. They landed with their observatory instruments in August, 1768, and fixed up a temporary observatory. During the winter, the cold was intense.[12] Other observations of the transit of Venus were taken at Quebec by Samuel Holland,[13] Surveyor General of Lands, and at Isle Coudre, near Quebec, by Thomas Wright,[14] Deputy Surveyor of the Northern District. An English expedition was made also to Otaheite,

an island in the Society Archipelago, in the South Pacific Ocean.

Observations at Philadelphia and vicinity. As to preparations made in the American colonies, Elias Loomis says:[15] "The American Philosophical Society. in January, 1769, appointed a committee of thirteen to observe this rare phenomenon. The gentlemen thus appointed were distributed into three committees for the purpose of making observations at three different places: viz., in the city of Philadelphia; at Norriton, 17 miles north west of Philadelphia; and the light-house, near Cape Henlopen, on Delaware Bay. Dr. Ewing had the principal direction of the observatory in the city, Rittenhouse at Norriton, and Mr. O. Biddle at Cape Henlopen. Some money was appropriated by the Philosophical Society toward defraying the expenses of the observations; but this being found insufficient, aid was solicited and obtained from the Assembly." David Rittenhouse had a brother, Benjamin, who assisted at the transit observations. Benjamin was a clock-maker, a member of the American Philosophical Society, and, during the Revolution, was superintendent of the Gunlock factory of Pennsylvania.

The Assembly of the province displayed a liberality in support of letters and science which puts to shame the penurious policy followed over half a century later by the Congress of the United States. Says a recent writer:[16] "In the session of 1768-69, the Assembly appropriated one hundred pounds sterling to the purchase of a reflecting telescope, with a micrometer, for the purpose of enabling the Philosophical Society to observe the transit of Venus; and shortly afterwards, at the same session, gave an additional sum of one hundred pounds, to defray the expense of erecting observatories. In 1771, they granted to Dr. Rittenhouse the sum of three hundred pounds, by a resolution which expressed that it was given 'as a testimony

of the high sense which the House entertains of his mathematical genius and mechanical abilities in constructing his orrery.' " Compare this expression of interest in science with the ridicule heaped upon President John Quincy Adams when, many years later, he recommended to Congress the erection of an astronomical observatory.

Professor Loomis gives further details of the preparations made in Pennsylvania for observing the transit of Venus in 1769: "Temporary observatories were erected, tolerably well adapted to the purposes for which they were designed. A reflecting telescope with a Dolland micrometer was purchased in London by Dr. Franklin, with the money voted by the Assembly; another of the same character was presented by Thomas Penn, of London; and other instruments were supplied in sufficient number. The observations at the three stations were all successful, and an account of them is given in the first volume of the Transactions of the American Philosophical Society." This volume is the first American scientific book containing research carried on in this country which attracted wide attention among European scientists. We may add that Rittenhouse was among the very first to complete the calculation of the solar parallax from the data taken by him at Norriton and the data secured at Greenwich for the transit. He obtained for the solar parallax 8.″805, which is very close to present adopted value 8.″802. Rittenhouse displayed keen observational power in noting that the entire circular outline of Venus was visible when a part was off the sun. He and others suggested that Venus has an atmosphere, a fact that was verified a century later by the observation of Theodore Lyman and the explanation of Henry N. Russell.[17]

Benjamin Franklin communicated to the Royal Society of London observations taken by Owen Biddle and Joel Bayley[18] at Lewestown at the mouth of Delaware Bay, a locality whose longitude and latitude had been carefully

determined by Mason and Dixon. A reflecting telescope was used in the transit observation, which belonged to the Philadelphia Library Company.

Observations at Providence and Boston. The transit was observed in Providence by Benjamin West, and in Boston by Professor John Winthrop of Harvard College. Winthrop could only observe the first two contacts of this transit as the last two occurred at sunset. Maskelyne, the British astronomer-royal, had urged Winthrop to go to the region of Lake Superior, where both the beginning and end were visible, but his health would not permit him to take this long and rigorous journey.[19]

In studying the effect of the aberration of light upon the time-data for the transit of Venus, Winthrop arrived at conclusions exactly the opposite of those reached by two English writers. Says Winthrop:[20] "I find that Mr. Bliss and Mr. Hornsby in their calculations in the Philosophical Transactions suppose the phases of the transit of Venus, to be accelerated by the equation of the aberration of light which amounts to 55″ of time. According to my idea of aberration I should think the transit would be retarded by it." That is, the observation of contact was made *after* its actual occurrence. Winthrop's conclusion was supported in the Philosophical Transactions by Richard Price.

1. *Philosophical Transactions,* Vol. 54 for the year 1764, London, 1765, p. 279.
2. *Philosophical Transactions,* Vol. 54 for the year 1764, London, 1765, p. 280.
3. T. L. Heath, *Aristarchus of Samos,* Oxford, 1913, p. 21. On the Arabic use of this instrument, see Karl Schoy, *Ueber den Gnomonschatten und die Schattentafeln der arabischen Astronomie,* Hanover, 1923.
4. Humboldt, *Political Essay on the Kingdom of New Spain,* translated by J. Black, London, Vol. 1, 1811, p. LX.
5. *Philosophical Transactions,* Vol. 54, 1764, p. 283.
6. *Transactions of the American Philos. Society,* Vol. I, 2d edition, Philadelphia, 1789, p. 164.
7. Humboldt, *Political Essay on the Kingdom of New Spain,* translated by J. Black, Vol. I, London, 1811, p. XXIX.

8. *Philosophical Transactions,* Vol. 60 for the year 1770, London 1771, p. 551.

9. Humboldt, *Political Essay on the Kingdom of New Spain,* translated by J. Black, Vol. 1, 1811, p. LII.

10. *Loc. cit.,* p. LIII.

11. R. Grant, *History of Physical Astronomy,* London, 1852, p. 431.

12. *Philosophical Transactions, London,* Vol. 59, p. 467; Vol. 60, p. 100, 137.

13. *Loc. cit.,* Vol. 59, p. 247.

14. *Loc. cit.,* Vol. 59, p. 273.

15. E. Loomis, *The Recent Progress of Astronomy,* 3d edition, 1856, p. 203.

16. *Memoirs of the Historical Society of Pennsylvania,* Vol. I, Philadelphia 1864, p. 158, 159.

17. See W. C. Rufus in Popular Astronomy, Vol. 29, 1921, p. 11.

18. Philosophical Transactions, London, Vol. 59, p. 414.

19. F. E. Brasch, "John Winthrop (1714-1779)," in *Publications of the Astronomical Society of the Pacific,* No. 165, August-October, 1916, Reprint, page 13, also pages 5-12. See also Joseph Lovering in *The Memorial History of Boston,* Vol. IV, 1881, p. 493-496.

20. *Philosophical Transactions,* Vol. 60, for the year 1770, London, 1771, p. 358.

CHAPTER VI

COMETS

Comets were a subject of attention and solicitude in the New World, as well as in the Old. As early as 1653, Gabriel Lopez de Bonilla, an astronomer and mathematician in the city of Mexico, published[1] a *Discourse* on the comet that appeared in December of that year. At Roxbury, Mass., Rev. Samuel Danforth observed a comet in 1652.[2] In the records of his church he incorporated various meteorological and astronomical data: "Anno 1652, 9th day, 10th month. There appeared a comet in y^{e} heaven in Orion, which continued its course tow^{d} o^{r} zenith f^{r} y^{e} space of a fortnight, viz. till Mr. Cotton's death." Danforth observed a comet in 1664, and in 1665 he published an *Astronomical Description of the Comet of 1664, with brief theological applications thereof.* In the church records at Roxbury the following epitaph commemorates his science:

> Non dubium, quin eó iverit, quo stellae eunt
> Danforthus, qui stellis semper se associavit.
> (No doubt gone where the stars are coursing
> Hath Danforth who always had the stars been nursing.)

At Lima, in Peru, Francisco Ruiz Lozano of the university in that city observed a comet in 1660 and is said to have anticipated Europeans in the detection of it.

The famous comet of 1680, which seemed to approach dangerously near to the sun, and the comet of 1681 were observed and discussed in Europe and America. Increase Mather in Boston (in 1685 elected President of Harvard College) expressed views everywhere widely prevalent at

that time; he preached a sermon on "Heaven's Alarm to the World . . . wherein is shown that fearful sights and signs in the heavens are the presages of great calamities at hand."[2] While no opposition to Increase Mather's views appeared in print in New England, it is very probable that men like Thomas Brattle held more liberal opinions than Mather on this question, as they did on other questions of theology. Sir Isaac Newton in his *Principia* (Bk. III, Prop. 41) gives observational data on the comet of 1680 taken in Boston on November 18, 19, 20, 22, 24. We are informed by Baily[3] in his account of the Astronomer Royal Flamsteed that the unnamed person to whom Newton refers is Thomas Brattle. It seems that Flamsteed and Brattle had been in correspondence. Baily says: Mr. Thomas Brattle of Boston in New England is the anonymous person alluded to by Newton in his *Principia* as having made such good observations of the comet of 1680: but he says, in his letter to Flamsteed, that he took no great pains on the subject." However, Newton states that "he was informed by Dr. Halley" of the observations in Boston. When observing the comet in 1680 Thomas Brattle was 23 years old. He had graduated from Harvard College in 1676; for twenty years after 1693 he served as treasurer of the College .

In the same place in the *Principia* Newton refers to observations on the comet, taken on November 19, 1680, by "Mr. Arthur Storer, at the river Patuxent, near Hunting Creek, in Maryland." This locality is about thirty miles south-east of the present city of Washington. Newton refers to this observer a second time: "And Mr. Storer (by letters which have come into my hands) writes that in the month of December, when the tail appeared of the greatest bulk and splendour, the head was but small, and far less than that which was seen in the month of November before sunrising; and, conjecturing at the cause of the

appearance, he judged it to proceed from there being a greater quantity of matter in the head at first, which was afterwards gradually spent."

In Brazil the comet of 1680 was observed by a German Jesuit, Valentin Stansel, who had taught rhetoric and mathematics at Olmütz and Prague; later he became attached to the Jesuit College of San Salvador (Bahia) in Brazil, where he took astronomical observations, particularly on comets. These observations were sent to Europe and published in Latin in 1683, at Prague. Notices of this book appeared in the *Acta eruditorum* of Leipzig of 1683. Sir Isaac Newton, in his *Principia* (Book III, Prop. 41), refers to Stansel's observations in Brazil on March 5, 1668, of a comet "with a head so small as scarcely to be discerned, but with a tail above measure splendid, so that the reflection thereof from the sea was easily seen by those who stood upon the shore, . . . but this excessive splendor continued only three days."

Controversy in Mexico. At the City of Mexico a discussion took place on the comet, which touched theological as well as scientific considerations. Cárlos de Sigüenza y Góngora, interested in mathematical, philosophical and antiquarian subjects, some of whose researches we have already considered, enjoyed wide reputation in his day. He was born in the city of Mexico[4] in 1645, devoted himself to intellectual pursuits and became professor of cosmography and mathematics at the Royal University of Mexico. He was the first to prepare a general map of Mexico. His name crossed the seas; Louis XIV invited him to pursue his scientific work in Paris,[5] but Sigüenza preferred to remain in his native land. He was probably the foremost seventeenth century American student of the mathematical sciences. We shall see that, in controversies with two men of European training, Sigüenza made nearer approach to modern concepts of nature than did his adversaries. He published at Mexico

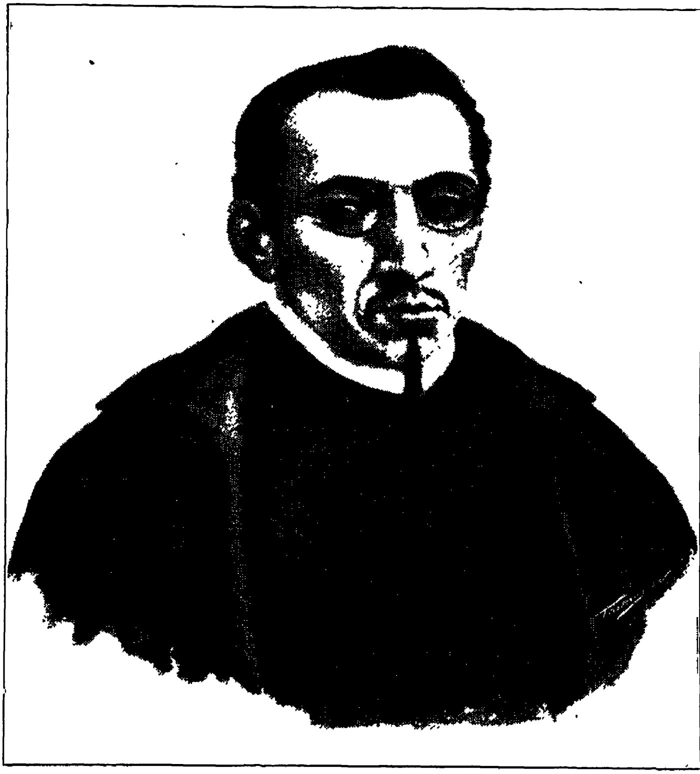

Fig. 26. Carlos de Sigüenza y Góngora.

in 1681, a *Manifesto* intended to reassure the people that comets were not tokens of the wrath of heaven. His liberal opinions were opposed by Martin de la Torre, a Flemish nobleman who in a pamphlet[6] upheld the old and popular view that comets were signs of approaching disaster. Sigüenza replied with a tract[7] on "Mathematical Bellerophontes against astrological Chimeras." There was published in the same year, 1681, also a "Discourse cometological" by Joseph de Escodar Salmeron y Castro. This author was medical professor at the University. To this strange document which made the declaration that the comet was an exhalation of dead bodies and of human perspiration, Sigüenza made no reply. Most prominent and able among the critics of Sigüenza was the Jesuit, Eusebio Francisco Kino, who had just arrived from Spain and later became a pioneer missionary explorer in California. Born at Trent in Trentino, Kino had studied in Germany and distinguished himself at Freiburg and Ingolstadt in mathematics. He refused the offer of a professorship in the University of Ingolstadt, to become a missionary to heathen lands.[8] While waiting for a chance to cross the Atlantic, he took observations at Cadiz on the comet of 1680. When he arrived in Mexico he at once entered into the public discussion started by Sigüenza. Kino published at Mexico in 1681 a pamphlet under the title: "Astronomical Explanation of the Comet" presenting an able argument but using a tone not altogether free of arrogance. Sigüenza prepared a reply touching theologic and scientific questions. It was written in 1681 but did not appear in print until 1690. It was entitled *Libra astronómica y philosofica,* a title which Farther Orazio Grassi had used in a reply to Galileo on the Comet of 1618. The prologue of the book was written by a hydrographer of high standing in Mexico, Don Sebastian de Guzman, a pupil of the mathematician, Ruesta. This prologue indicates some of the scientific questions that came under

discussion, questions of parallax, of astronomical refraction, of whether the paths of comets were rectilinear as had been claimed by Kepler or a conic or helixes formed in accordance with Descartes' theory of vortices. Sigüenza challenged the reliability of Kino's observations, on the ground that the comet of the year 1680 could not be observed with accuracy in Europe because of its great declination and of its appearance in twilight.[9] Another publication on comets, from the pen of Gaspar Evelino[10] appeared at Mexico in 1682.

We have dwelt at some length upon Sigüenza and his controversy on comets, because this debate is the earliest instance of a clash of intellects in public print on a scientific question that occurred in America. This controversy, conducted in a region far remote from the recognized centers of intellectual life, was very creditable and indicated that even distant America affords examples where in the seventeenth century the scientific method was arrayed in battle against the antiquated processes of theology and superstition.

1. Our information is drawn from Justin Winsor *Memorial History of Boston,* Vol IV., Boston, 1881, pp. 490, 491.
2. See A. D. White, "A History of the Doctrine of Comets" in *Papers of the American Historical Association,* Vol. XI., New York and London, 1887, p. 29.
3. Francis Baily, *An Account of the Rev. John Flamsteed,* London, 1835, p. 705.
4. J. T. Medina: *La Imprenta en Mexico* (1539-1821), Tomo II, Santiago de Chile, 1907, p. 415, 416.
5. *Mexico, Its Social Evolution,* Tome I, Vol. 2, Mexico, 1900, p. 436.
6. "Manifiesto Christiano en favor de los Cometas mantenidos en su natural significacion." See *México á Través de los Siglos,* Tomo II, p. 739.
7 "Belerofonte Mathematico contra la chimera astrologica." See Vol. II, p. 739, of *México á Través de los Siglos.*
8. H. E. Bolton: *Kino's Historical Memoir of Pimeria Alta,* Vol. I, Cleveland, 1919, Introduction, p. 29.
9. Jose Mariano Beristain y Souza, *Biblioteca Hispano Americana Setentrional,* 2 Ed., Tomo II, Amecameca, 1884, p. 127; Tomo III, p. 145. Several long quotations from the *Libra astronómica y philosofica* relating to longitudes, are found in Manuel Orozco y Berra's *Apuntes para la historia de la geografia,* 1881, p. 218-221.
10. Manuel Orozco y Berra, *op. cit.,* p. 219.

CHAPTER VII

ALMANACS

The following calendar verses the world has been unwilling to let die. They occur first in medieval Latin manuscripts, were translated into various modern languages, imported into the New World, and given in eighteenth century publications:

Thirty Days hath September	Treinta diás trae noviembre
April, June and November,	Con abril, junio y septiembre.
February twenty-eight alone,	A veintiocho sólo uno,
And all the rest have thirty-one.[1]	Los de más a treinta y uno.[2]

In the American colonies some attention was early directed to the computation of almanacs. Of 44 almanacs issued in Massachusetts before 1687, 41 were prepared by twenty six graduates of Harvard College, ten of whom were at the time tutors in that institution.[3] We are told that before 1651 the "godly Mr. Sam Danforth who hath not only studied divinity, but also astronomy . . . put forth many almanacs" and "was one of the fellows of the college." Nathaniel Ames neglected his medical practice to prepare his *Astronomical Diary and Almanac.* Jacob Taylor, a colonial surveyor in Pennsylvania, was active in this line. In an almanac of 1675, John Foster advanced strong arguments in favor of the Copernican system, as did also Nathaniel Mather in an almanac of 1686. Samuel Stearns, who after the close of the War of Revolution was imprisoned at Worcester, Mass., for being a loyalist, computed an almanac while in confinement. In an almanac of 1787, printed in Boston, he wrote: "Eighteen years have revolved

since I first published astronomical calculations, and for some years past I have annually calculated for four governments on this continent." Almanacs were published by Benjamin West of Providence (about 1767) and Professor Nehemiah Strong of Yale (about 1783-1807).

One of the earliest Mexican publications of this sort was the *Calendario perpetuo* by Fray Aljo Garcia who died in 1579.[4] In the university at Lima, Peru, José Ramón Koenig of the chair of mathematics (established in 1657, with the Mexican scholar Francisco Ruiz Lozano as its first occupant), started in 1680 the publication of the *Conocimiento de los tiempos*.[5] This annual publication was continued to the end of the eighteenth century by Koenig's successors in that chair, Pedro Peralta Barnuero y Rocha, the Bohemian Jesuit Juan Rer, and the Spanish-American Cosme Bueno. It contained astronomical data based on tables issued in Europe, also geographical and nautical data of local value. The first almanac of Bogotá in Colombia was printed in 1788.[6]

Astronomical Hand. Worthy of more than passing notice is a booklet that appeared in Mexico, in which the dates of catholic feasts for different years are computed by a special form of finger-reckoning. It is well known that computation on the fingers was in vogue, more or less, among the Greeks and Romans, but was gradually abandoned in Europe after the sixteenth century, except in Roumania and in isolated places among the French peasants.[7] Traces of it are found also in the United States in a few very small foreign settlements. The Mexican publication uses the fingers of the left hand. We have not been able to find this very specialized process of finger-reckoning in European authors.

The booklet in question, covering thirty pages, was brought out in the City of Mexico in 1757 by a priest, Buenaventura Francisco de Ossorio, under the title *Astronomica, y*

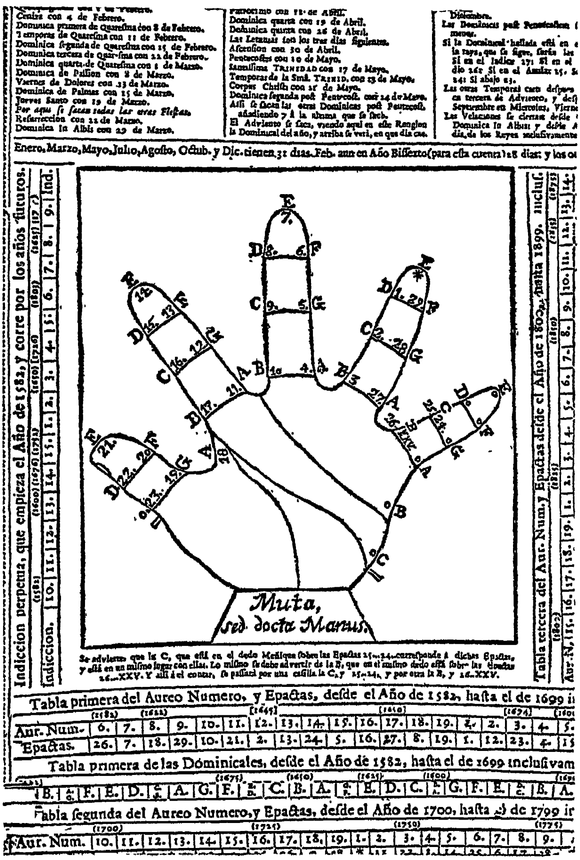

Fig. 27. "The Astronomical Hand."

Harmoniosa Mano. There are two copies of it in the Bancroft Library of the University of California, and my attention was called to them by Professor H. I. Priestley. Judging by the statements in the dedication of the book and in the printing privilege, the process was original with Ossorio. In the adjoining illustration the astronomical and

metrical Hand—the "mute but learned hand,"—is reproduced. For the determinations of the dates of feasts, two fundamental data are taken from the tables placed on the border of the large sheet on which this Hand is drawn. In the figure given here, there is reproduced only a part of the border. One of these data is the Sunday or *dominical* letter of the year under consideration—one of the seven letters A, B, C, D, E, F, G. In every year, January first was marked A, January second was marked B, January third C, and so on. The letter which in a common year falls on Sunday is the dominical letter for that year. A leap year has two dominical letters, one for January and February, and the preceding letter for the remaining months (G being taken to precede A). The second of these data is the number, called the *epact,* which, in the new style of the calendar, means the age of the moon on the first of January; it is one of the numbers 1, 2, 3, ..., 29.

Suppose we desire to know on what date Easter Sunday came in the year 1735. From the tables bordering the Hand we find that the dominical letter for that year was B, the epact was 6. Having these data one proceeds by using the astronomical Hand. All the capitals drawn upon it are dominical letters; all the numbers are epacts. Find the place on the Hand marked 6. It is on the middle finger. From this 6 move along the finger-edges toward the right till the letter B is reached; this is at 3. From the marginal data we learn that, to find Easter, we must always begin with March 22. We start at the point 22, on the thumb, and advance toward the right, following the outline of the fingers and counting "March 23" when we are at 21, "March 24" then we are 20, and so on. When we arrive at 3 we shall have reached "April 10". This was the date of Easter Sunday in the year 1735, new style.

If one wishes to find Ascension day for 1735, use the same position 3 on the Hand. The marginal data show

that we must begin with April 30. As before, start at 22 and when 3 is reached, you will have counted to May 19, which was the date of Ascension day in 1735. This same process was used for over thirty movable feasts in the Catholic calendar.[8]

1. Nicolas Pike, *New and Complete System of Arithmetic*, Newburyport, 1788, p. 45.
2. Almanac printed at Bogotá, 1788. See Pedro M. Ibáñez, *Crónicas de Bogotá*, 2d. Ed., Vol. 2, Bogotá, 1915, p. 4.
3. Charles L. Nichols, *Notes on the Almanacs of Massachusetts*, Worcester, 1912, p. 6.
4. *Obras de D. J. Garcia Icazbalceta*, Mexico, Tomo 1st, 2d Ed., 1905, p. 41.
5. J. T. Medina, *La imprenta en Lima*, Vol. 2, 1904, p. 297, 300, 457-459; Vol. 3, 1905, p. 163, 359.
6. Pedro M. Ibáñez, *Crónicas de Bogotá*, 2d Ed., Vol. 2, Bogotá, 1915, p. 4.
7. P. Treutlein, *Abhandlungen zur Geschichte der Mathematik*, Vol. I, Leipzig, 1877, p. 21.
8. For additional details see F. Cajori in *Isis*, Vol. 8, 1926, p. 325-327.

CHAPTER VIII

ORRERIES

In the seventeenth and eighteenth centuries, when the astronomy of Copernicus, Kepler, Galileo and Newton was acquiring firm hold upon the popular mind, it became a pleasing fancy to contrive mechanical devices which would exhibit to the eye the revolutions of the planets around the sun. Such "planetariums" were first constructed by Huygens and Römer. One of the early machines exhibiting also the motion of the various known satellites was made at the instance of the British statesman and dramatist, Roger Boyle, Earl of Orrery. As a compliment to him, these machines came to be called "orreries." An orrery differs from a planetarium in exhibiting more fully the motions of bodies in the solar system—the diurnal as well as the annual motions of the earth, the revolution of the moon and perhaps also the motions of Jupiter and all the other known planets. In the library of Christ Church, at Oxford, there is a unique collection of orreries of English manufacture, representing "the instrumental equipment of the amateur astronomer of the beginning of the eighteenth century."[1]

Perhaps the first in America to undertake the manufacture of an elaborate contrivance of this sort was Rittenhouse,[2] whose "orrery exhibited with surprising accuracy the motions in space of the various bodies of the solar system. In a paper which Rittenhouse read on March 21, 1786, he remarks that "the clock part of it may be contrived to

play a great variety of Music," thereby suggesting a veritable "harmony of the spheres" that would have delighted Pythagoreans. The orrery attracted general attention. A lively competition sprang up between the College of Philadelphia (now the University of Pennsylvania) and the College of New Jersey (Princeton) for the possession of this orrery. New Jersey won out and Rittenhouse afterwards made another orrery for the institution in his own city.

The author of the Vision of Columbus, a poem first published in 1787, alludes (Book VII) to the Rittenhouse orrery:

> "See the sage Rittenhouse, with ardent eye,
> Lift the long tube and pierce the starry sky;
> Clear in his view the circling systems roll,
> And broader splendours gild the central pole.
> He marks what laws th' eccentric wand'rers bind,
> Copies Creation in his forming mind,
> And bids, beneath his hand, in semblance rise,
> With mimic orbs, the labours of the skies.
> There wond'ring crowds with raptur'd eye behold
> The spangled heav'ns their mystic maze unfold;
> While each glad sage his splendid hall shall grace,
> With all the spheres that cleave th' ethereal space."

Boston had its orrery as well as Philadelphia and Princeton. It was constructed by Joseph Pope who completed it in 1786, after ten years of labor.[3] Interest in the mechanical representation of the solar system and the motions of its parts was displayed also at Yale where, as recorded in the diary of President Stiles,[4] there was under construction, in February, 1784, in the college library, "by Joseph Badger a Jun. Sophister of a mechanical genius and a Joyner," a planetarium six feet in diameter.

1. R. T. Gunther, *Early Science in Oxford,* Vol. 2, Oxford, 1923, p. 2. See also p. 267-272.

2. *Trans. Am. Phil. Soc.,* Vol. 1, 1789,, p. 3.

3. For details see "Boston and Science" by Joseph Lovering in *The Memorial History of Boston,* Vol. 4, Boston, 1881, Chap. IX, p. 500-502. A description of Pope's Orrery was printed in the *Memoirs of the Am. Acad. of Arts and Sciences,* Vol. II, Part 2, p. 43.

4. *The Literary Diary of Ezra Stiles,* Vol. III, p. 113.

CHAPTER IX

THE EARLIEST PERMANENT OBSERVATORY IN AMERICA

The earliest permanent astronomical observatory on the American continent was erected in 1803 at Bogotá in New Granada (the present Colombia), a city which at the beginning of the nineteenth century had the reputation of being "the Athens of South America." We shall see that this reputation is primarily due to two scholars, one a Spaniard, the other a native of Colombia. But we must preface some general remarks on early temporary observatories in America.

Temporary Observatories. It will be recalled that Count Maurice of Nassau-Siegen, in 1639, built an astronomical observatory for George Marcgrave, on the island of Vaez in Brazil. Colin Campbell had an observatory, in 1732, on the island of Jamaica. Humboldt speaks of the observatory of Bonaventura Suarez in Paraguay. No doubt a number of temporary structures were put up in other localities. To observe the transit of Venus in 1769, temporary accommodations for astronomical instruments were erected by Chappe and by Velązquez in Lower California, and by William Wales at Hudson's Bay. We know also that in 1769 David Rittenhouse had an observatory at Norriton, near Philadelphia. Later he abandoned it and built for himself another temporary observatory on his "observatory lot" in Philadelphia. It was a "small but pretty convenient octagonal building in the garden adjacent to his dwelling" at the corner of Arch and (Delaware) Seventh streets.[1] There was also a short-lived observatory at William and Mary College in Williamsburg, Virginia, where in 1789 James

Madison, president of the College, made observations. He said: "As the observatory in which the transit instrument had been formerly placed, was not, at this time, rebuilt, I was not enabled to attend to the going of the time-keeper, by means of such observations as I wished to have made."[2] His equipment included a sextant and an achromatic telescope magnifying about 60 times. He observed the lunar eclipse of November 2, 1789 and the transit of Mercury, November 5, 1789. He includes reports made by Robert Andrews, professor at William and Mary, with a reflector by Short magnifying 90 times. Andrews, together with John Page, and John Lukens built, in 1784, a temporary observatory at Wilmington, Delaware, to determine the position of that locality, preparatory for a survey of the boundary between Pennsylvania and Virginia.

Mutis at Bogotá. The scientific movement at Bogotá in the present Colombia was started by the Spanish scholar, José Celestino Mutis. He[3] was born in Cadiz in 1732, graduated in medicine at the university of Seville in 1757, and then spent three years in Madrid where he devoted himself ardently to the study of mathematics, physics, astronomy and especially botany. When a new viceroy of New Granada (our Colombia) assumed office, Mutis accompanied him. In 1762, he was assigned the chair of Mathematics and Astronomy in the Colegio del Rosario, but the chief effort of his life in Bogotá was botany. Noted is his study of Cinchona bark, the source of quinine. He was the first to teach the Copernican system in New Granada; he observed the hourly variations of the barometer. He took astronomical observations, but unfortunately never published them. He and Alexander von Humboldt were great friends. That his early interest in astronomy did not wane is evident from the fact that he founded an observatory in 1803, and became its first director. He trained many scientists, notably Francisco José de Caldas, who was in

Fig. 28. José Celestino Mutis.

full charge of the observatory for eight years after the death of Mutis in 1808. When in Bogotá, Mutis was in correspondence with scientific men, including the celebrated botanist Karl von Linné at Upsala in Sweden. Mutis was not a highly trained mathematician and astronomer. In letters and addresses he refers to such writers of elementary texts in mathematics, as the German Christian Wolf, and the Spaniard Benito Bails. Nevertheless, Mutis succeeded by his winning personality in infusing interest in mathematical studies, among pupils in Bogotá. After his death, his scientific papers were taken to Spain and kept in a Madrid library, where at one time they were discovered to be a resting-place for cats.[4] In recent years his work has received due recognition through the extensive biography prepared by A. F. Gredilla.

The observatory was built before the time when the now familiar dome-shaped astronomical buildings came into vogue for the housing of equatorially mounted telescopes. The observatory at Bogotá was a costly structure, built for the advancement of science and also as an ornament to the capital of New Granada. We reproduce a photograph of it. It was designed by the Capuchin Fray Diego Domingo Petréz, and aimed at both beauty and solidity. He also supervised its construction which was begun on May 24, 1802 and was completed on August 20, 1803. It is located 2645 meters above sea level. The astronomer Caldas called it, "the first temple erected to Urania in the New Continent." It was an octagonal tower, 4.2 meters along each side and 18.19 meters high. The photograph exhibits the Tuscan pilasters fitted to the angles of the octagonal structure.[5] The first story had one room, the inside diameter of which was 8.3 meters. The room on the second story had a hemispherical ceiling, with an opening in the center, admitting a ray of light, forming an image of the sun on the floor. A north and south or meridian line was drawn upon the

floor. There was thus formed a gnomon, 11.6 meters high, enabling one to ascertain the time of noon, and the elevation of the sun as it passed the meridian.

On the south east side of the principal octagon structure was a tower providing a spiral stair way; it shows prominently in our photograph. Above the stairway was a small room for taking observations. In a north and south vertical position there was located here, for the determination of meridian altitudes of stars, an astronomical quadrant such as had been used for this purpose by Tycho Brahe and Flamsteed. The roof of this tower was replaced in 1881 by a metallic cupola.

The observatory building cost 13,815 pesos (= dollars) and 1½ reales, which is a large sum for that time in Bogotá. In 1811, three years after the death of Mutis, when clouds had gathered in the political sky, the Tribunal de Cuentas ordered the cost of the observatory paid out of the Mutis estate.

Some of the instruments for observation were supplied by the Spanish government, through the persuasion of Mutis, while others were donated by José Ignacio Pombo of Carthagena, a Colombian patron of the sciences and letters. Thus in 1803 there was at Bogotá an astronomical observatory provided with instruments and books, such as existed at that time at no other locality in the new continent.[6]

Caldas. Mutis and Francisco José Caldas, his successor as director of the observatory, were observors who displayed zeal for research. Caldas took charge in 1805. He is the most distinguished student of the mathematical sciences that Colombia has produced. He did not come under the scientific guidance of Mutis until about 1801 and before that time was greatly hampered by lack of books and instruments needed for the mastery of the elements of these sciences. Caldas was born at Popayán, Colombia, in 1771.

Fig. 29. The astronomical Observatory at Bogotá.

In a letter to Mutis (Aug. 5, 1801) he describes his struggles for scientific education.[7]

At the age of sixteen, he acquired a craving for mathematical studies. Though not regularly taught at the school he attended, he was able to make a beginning in arithmetic, geometry, trigonometry, algebra and physics, through a friendly professor, and under the guise of a course in philosophy. He was then sent to a law school where he "lost three of the most precious years of his life." When at last he could follow more freely his own inclinations, he accidently secured four scientific books and, when time permitted, he resumed the study of mathematics. He wished to apply them to astronomy, but lacked all instruments. He made a gnomon, which was simply a rod placed vertically on a level surface, and measured the meridian altitude of the sun by the lengths of the gnomon and its shadow. In 1796 Caldas went to Bogotá on a business trip and came upon the astronomy of Lalande and the Elements of Mathematics of Bossut, belonging to French officers of marine. He copied solar tables and was able to purchase a barometer and a reflecting octant. A boundary dispute between two localities induced him to determine longitudes. He did this by observing the eclipse of the moon on December 3, 1797, with improvised equipment. This was the beginning of a map of the territory of Timana, which he concluded in 1798. But he was dissatisfied with his lack of facilities for accurate determinations and he turned for a while to the study of botany. Later he came under the guidance of Mutis and of Humboldt, and he returned to astronomy.

The ten years following 1805 were the happiest in the life of Caldas. He devoted himself altogether to science. This work was mainly along the line of the determination of longitudes and latitudes, elevations above sea-level, the gathering of thermometric and barometric data, and the

preparation of maps of localities in Colombia. By these labors he was of great service to his native country.

That scientific activity may continue in a community, there must exist some periodical for the publication of results and the dissemination of the knowledge obtained. Caldas in 1808 started the *Semanaria* and served as its editor. It was devoted to science and literature. It continued for about two years and contained some accounts of Caldas' own work. After that appeared Caldas' *Memorias cientificas* which were really a continuation of the *Semanaria,* but lasted only one year.[8] A centennial edition of the works of Caldas was brought out by E. Posada.[9] The revolutionary period at Bogotá was one of very creditable scientific achievement. "The atmosphere was propitious for varied scientific activities," says Ibáñez,[10] who proceeds to enumerate over a dozen writers on natural history, geography, astronomy, botany, agriculture, archeology, medicine, law and painting.

But the revolutionary movement which started in 1810, put an end to scientific pursuits. Caldas became chief of engineers in the patriotic army. Though he was not actively engaged in the field, the Spaniards captured him in 1816. From his prison cell he made appeals to be permitted to continue his scientific work, but in vain; he was shot. Thus in the prime of life, passed away the most conspicuous astronomical worker that Colombia produced. "Venerated by all Colombians is the memory of Caldas."[11]

Unfortunately, independence from Spain brought a complete suspension of astronomical work. As a result, after the first ten years, for three quarters of a century, the observatory at Bogotá did not contribute to the progress of science. We are informed[12] that in 1823 it was "absolutely abandoned," as was also the botanical garden of Mutis. More detailed information on the observatory is given by a traveller of 1836-1837:[13] "The Observatory is an octagonal tower about sixty feet high, I should think, having but two rooms

besides the empty and dilapidated one on the ground floor, where formerly a fine fountain emptied its waters into a large basin of hewn stone, but which is now entirely dried up. Two fine Dollond telescopes, with other instruments, were destroyed, when the Patriots entered the city, by a band of woolly Africans, who forcibly made their way into the place, and broke out the glasses and otherwise mutilated the instruments, because they looked upon them as machines by means of which their enemies, the Spaniards, warred against them. The Library consists of some fine volumes, principally in the Spanish and French languages, treating generally of the arts and sciences. Among them is a very ancient and rare work on Botany. But the load of dust upon these fine works too truly tell in what bad repute reading is generally held in this place; while the careless and slovenly manner in which the rooms are kept augurs but poorly for the cause of literature and science in the capital of New-Granada."

During the nineteenth century, the higher institutions at Bogotá devoted themselves to the study of the humanities and paid hardly any attention to pure science. Not before 1894 were publications issued from the observatory, indicating the resumption of astronomical work. Since 1922 special emphasis is placed at the observatory, upon meteorological and magnetic observations.

1. Goode, "The Origin of the national scientific and educational institutions of United States." *American Historical Association Papers,* Vol. IV, Part 2, 1890, p. 310.
2. *Transactions of the American Philosophical Society,* Vol. 3, 1793, p. 150.
3. A. Federico Gredilla, *Biografia de José Celestino Mutis,* Madrid, 1911, p. 12-16.
4. Phanor James Eder, *Colombia,* London, [1913], p. 4.
5. A description of the observatory was written by Caldas in the *Semanario* of Feb. 14, 1808. See *Obras de Caldas,* edited by Eduardo Posada, Bogotá, 1912, p. 271-275. Consult also Julio Garavito, *Reseña histórica del Observatorio de Bógotá,* Bogotá; Diego Mendoza, *Expedición de José Celestino Mutis,* Madrid, 1909, p. 132.

6. Caldas in his article in the *Semanario* of Feb. 14, 1808, enumerates the following instruments sent by the Spanish government: a quadrant by Sisson, two theodolites by Adams, two chronometers by Emery, two thermometers by Nairne, two portable compasses and six dozen tubes for barometers. Three boxes of additional instruments intended for the observatory were lost at Cadiz. Instruments secured from other sources were four Dollond achromatic telescopes of different lengths, three Dollond reflecting telescopes, one graphometer, octants, artificial horizons, compass needles, Dollond thermometers, barometers, globes, small spy-glasses, etc. Caldas was happy in possessing a fine astronomical pendulum which had been used in Ecuador by the Spanish and French and sold by La Condamine to Father Terol who was interested in clock making. Upon the death of the latter the instrument passed through several hands and was finally acquired by the Observatory. Caldas had also a quadrant of John Bird, 18 inches in radius, with a micrometer, which Humboldt had used on his trip to the Orinoco. Of books, Caldas mentions the astronomical tables of Delambre, also Maskelyne's observations, and ephemerides of many years.

7. Diego Mendoza, *op. cit.*, Madrid, 1909, p. 134-139.

8. Ibáñez, *op. cit.*, p. 320.

9. *Obras de Caldas,* por E. Posada, Bogotá, 1912.

10. Ibáñez, *op. cit.*, p. 242.

11. *Obras de Caldas,* por E. Posada, Proemio.

12. Carlos Navarro y Lamarca, *Compendio de la Historia general de América,* Buenos Aires, 1913, Tomo 2, p. 303.

13. *Bogotá* in 1836-7, by J. Stuart, New York, 1838, p. 133.

Fig. 30. Statue of Francisco José Caldas, at Popayán.

CHAPTER X

PHYSICS

Physical experimentation in America before the opening of the nineteenth century is far from negligible. Some of the researches were carried on during travels or expeditions of European scientists; other researches were conducted by Americans. Among the former are the observations on atmospheric refraction.

Atmospheric refraction. Ptolemy was the first to notice that light from a star undergoes a change in direction as it enters the earth's atmosphere, but no attempt was made to correct apparent positions of the celestial bodies before Tycho Brahe whose table of refractions was very imperfect. The law of refraction of light was discovered by W. Snell in 1637. He showed that the sines of the angles of incidence and refraction bear a constant ratio to each other. The application of this to the atmosphere was far from easy. G. D. Cassini published tables in 1662 which corrected for the combined influence of parallax and refraction. But it became desirable to know the independent effects of these two elements. Jean Picard remarked in 1669 that probably refractions vary with the season of the year, and the different changes of the weather. Strangely Picard and Cassini thought they had reason to believe that refraction at the polar circle was double that at the parallel of Paris.[1] To explain the difference between the refractions of tropical regions and the temperate zone Bouguer set up the hypothsis that the nature of the atmosphere varied with the climate. Voyages were undertaken to determine atmospheric refraction at different altitudes above the sea-level. Cayenne, the Cape of Good Hope, Quito, places in India were visited at

different times by J. Richer, N. L. Lacaille, Bouguer and Legentil. The true explanation, to the effect that refraction is dependent upon atmospheric temperature and pressure, was advanced by Tobias Mayer and Lacaille, so that it is possible to construct tables of refraction which can be used in all climates and all parts of the world. Finally the observations made by Alexander von Humboldt during his travels in South America during the initial years of the nineteenth century helped to clear up this question.

Pendulum experiments. Our reference to Richer must be supplemented by the remark that when he was at the island of Cayenne in French Guiana, he made the notable observation that a pendulum adjusted at Paris to beat seconds lost at Cayenne two minutes daily.[2] He fitted up a single pendulum to vibrate in seconds, which were measured by an excellent clock; he determined the length of the simple pendulum and he repeated this every week during the ten months he staid at Cayenne. On his return to France he found his pendulum shorter by 1¼ lines than the seconds pendulum at Paris. This important observation bore on the then mooted question of the flattening of the earth. Christian Huygens calculated that at the equator the centrifugal force due to the rotation of the earth is $1/289$ of the central force of gravity, that at Cayenne the seconds pendulum should be $5/6$ of a line shorter than at Paris. Richer had made it more, namely, 1¼ lines shorter by observation. The difference appeared to be due to the flattening of the earth, so that, near the poles, the pendulum, being nearer the earth's center, would be attracted more strongly and would oscillate faster.

Pendulum experiments were made also by Godin, Bouguer and la Condamine, on their voyages in South America to measure the meridian. For example, la Condamine, when at the sea port Para, near the mouth of the Amazon river, used a pendulum 23 inches long, which continued its oscilla-

tions visibly for more than twenty-four hours. He found that it made daily, at Para, from 31 to 32 more vibrations than at Quito, and from 50 to 51 more vibrations than on the mountain Pichinchi in Ecuador.[3]

Further pendulum experiments were desirable and were undertaken in different parts of the earth. One noted observation was made in 1732 at the island of Jamaica in the West Indies, by Colin Campbell, a fellow of the Royal Society of London. The astronomer James Bradley[4] gave an account of these experiments, stating "He (Campbell) has furnished himself with an Apparatus of Instruments not unworthy the Observatory of a Prince; among which is a Clock whose pendulum vibrates Seconds, made by Mr. George Graham. . . . We received an account of the success of the experiment, by the Hands of Mr. Joseph Harris, (writer on navigation; master of the mint) who was present at the making of it in Jamaica, whither he went the year before with Mr. Campbell, in order to assist him in the design of erecting an Observatory for the Improvement of Astronomy, and the promoting of other parts of Natural Knowledge in that Island: But his ill State of Health obliging him to return into England, he brought with him the Original Journal of the Observations. . . " The clock went daily 1′ 58″ slower in Jamaica than in London. Bradley adds: "I esteem Mr. Campbell's Experiments to be the most accurate of all that have hitherto been made." Bouguer and others discussed experiments on the length of the seconds pendulum made at St. Domingo.[5]

Gravitational Attraction of Mountains. To test Newton's prediction that a large mountain caused a plumb line to deviate from its normal direction, Bouguer and la Condamine, when in Ecuador on meridian measurement, made observations on the attraction exerted by the lofty mountain Chimborazo. By measuring at opposite sides of the mountain the positions of a star, with instruments adjusted by the

aid of the plumb line or level, they found that the mountain caused a plumb line to deviate toward it by $7.''5$. Taking into account the size of the mountain and making certain assumptions regarding densities, a theoretical deviation was obtained, much greater than the one observed. It was therefore concluded that the mountain must contain great cavities, or be composed of material of comparatively small density.[6] Later opinion is that these observations were made with instruments hardly of sufficient accuracy to be altogether dependable.

Meteorology. Isaac Greenwood, the first incumbent of the chair of the Hollis professorship of Mathematics and Natural Philosophy at Harvard, was interested in meteorology and contributed to the Philosophical Transactions of London No. 401, p. 390, a method of keeping meteorological records (particularly wind records) at sea. His successor in that chair, John Winthrop, in 1742, began to take meteorological observations and continued them till 1763, using a Hawksbee thermometer filled with spirit of wine and, after 1759, also a Fahrenheit thermometer. At various times, Benjamin Franklin showed interest in phenomena of the weather. He advanced the idea that a storm may travel in a direction opposite to that of the wind, basing his novel claim upon the following experimental evidence: About 1740 in Philadelphia, one evening, he prepared to observe an eclipse of the moon due at nine o'clock. He was prevented by a storm from the north east. Observers in Boston saw the eclipse in a clear sky and did not have the storm until eleven o'clock. Evidently the storm travelled in a north east direction against the wind. Franklin advanced a theory of "whirlwinds and spouts"[7]

While crossing the Atlantic Ocean, Benjamin Franklin took temperature measurements of the gulf stream, the existence of which was unkown to some of the English sea captains. Beginning on July 12, 1785, Franklin took the

temperature of the "air and water . . . at noon, as well as morning and evening."[8]

Weather records taken at Ipswich in 1781-1783 by Rev. M. Cutler were published in the memoirs of the American Academy at Boston.

Sometime between 1780 and 1792 meteorological observations were taken at Bradford and Cambridge, Massachusetts, as a part of the work of an international Meteorological Society of the Palatinate, that was founded in 1780 at Mannheim, and for a dozen years had observers in Germany, Austria-Hungary, Switzerland, Italy, France, Belgium, Holland, Russia, Scandinavia, Greenland, and the two in Massachusetts. Altogether there were about forty observers. The various observations were published in twelve quarto volumes.[9]

Noah Webster, in the years 1790-1792, experimented on the formation of dew,[10] to settle "whether dew is the descent of vapour during the night or the perspiration of the earth" and concluded that it was mainly the latter. This investigation took place several years before William Charles Wells in England published his *Essay on Dew,* 1814. Moreover, Webster's conclusions are in closer accord with modern views than are those of Wells. David Rittenhouse speculated on the nature of shooting-stars; "may not these shooting stars," he asks, "be bodies altogether foreign to the earth and its atmosphere, accidentally meeting with it, as they are swiftly traversing the great void of space?[11] These words, written in 1783, express advanced views on a subject which in 1790 and even later were considered absurd by Bertholon in the *Journal des sciences utiles* and by other European scientists of standing; it was considered physically impossible that stones should fall from heaven.[12]

Electricity and Magnetism. The earliest published observations, electrical in nature, in America, were made by Isaac Greenwood, at Harvard College. Greenwood, on October,

1731, observed an unusually brilliant display of the Aurora Borealis. His study of it was an interesting application of the Baconian method of research, exhibiting its importance as well as its limitation.

"I am persuaded," he says,[13] "there is no better way to arrive at the true Cause of this extraordinary Phenomenon, than by attending to the minutest Particulars and Circumstances thereof, and if what I have done contributes thereunto, I shall esteem it a sufficient Excuse for the Number and Particularity of my Notes." He took great care to record observations on temperature, wind, dew, hoarfrost, barometric pressure, time of rise and decay of the auroral displays, their color-effects, the angular altitude of the streamers, etc. But the number of possible observations is unlimited, and it did not occur to Greenwood to observe the behavior of the compass needle. Before this, Halley had noticed that the summit of the aurora lay in the magnetic meridian. In 1741, O. P. Hjorter saw by accident that during auroral displays the magnetic needle was in violent agitation; Mairan observed that the dipping needle pointed directly to the spot to which rays converge. These magnetic observations were simply a few in a large mass of miscellaneous observations. In the absence of a theory connecting the aurora borealis with magnetism they meant but little. The Baconian method afforded no criterion for the selection of those that were vital. Among the first to form a *hypothesis* was Benjamin Franklin. He had advanced his one-fluid theory of electricity during the first year of his study of electricity. He called that fluid "electric fire." In a letter to Peter Collinson,[14] he makes the guess that the aurora borealis is an electric phenomenon. He says: "When the air, with its vapours raised from the ocean between the tropics, comes to descend in the polar regions, and to be in contact with the vapours arising there, the electrical fire they brought begins to be communicated, and

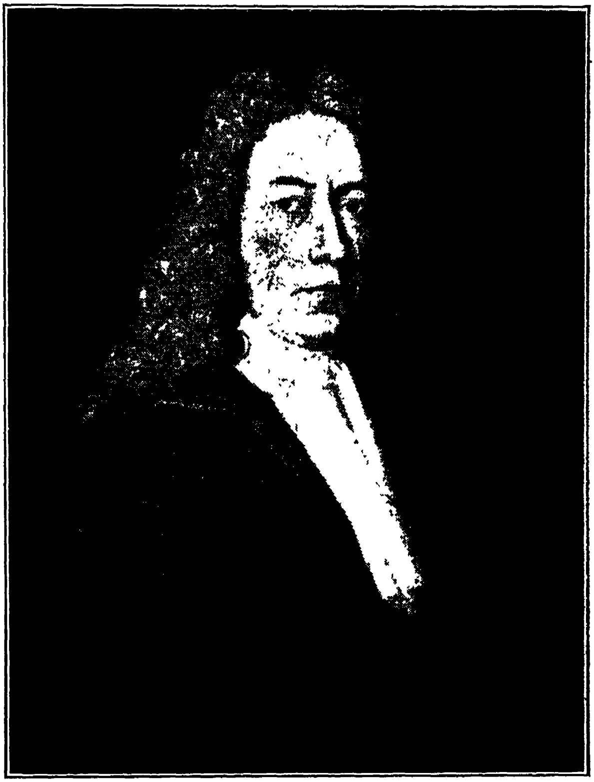

Fig. 31. Isaac Greenwood, first professor of Mathematics and Natural Philosophy at Harvard College. (Courtesy of F. E. Brasch.)

is seen in clear nights." Four years later he expressed himself in greater detail. Franklin's theory that the aurora is due to electric discharges in the upper air has maintained its place to our time.

About half a century later, an historical register of the aurora borealis from 1781 to 1783 was published by C. Gannett of Cambridge,[15] Mass. In 1789 there was in Mexico a display of aurora borealis, most rare in those latitudes, which was studied by Antonio Alzate.[16] Antonio de Leon y Gama wrote a *Disertacion fisica* on this phenomenon,[17] and was criticized by Francisco Rangel.

Another strange phenomenon, the auro australis, or southern polar light, was first described by the Spaniard Don Antonio de Ulloa, in his travels of 1735-1746 in South America: "At half-past ten in the evening" near the island of Tierra de Juan Fernandez, "we observed upon the summit of a neighboring mountain a very brilliant and extraordinary light. . . . This lasted three or four minutes, when the light began to diminish as gradually it had grown, and finally disappeared."[18]

The most important electrical researches carried on in America during the eighteenth century were those of Benjamin Franklin. He was one of two Americans of that century who played a truly conspicuous rôle in the advancement of physics. The other was Benjamin Thompson (Count Rumford). Though born in humble Massachusetts homes, in towns within two miles of each other, the two men never met. Rumford carried on his researches abroad, Franklin in this country. Rumford's investigations were mainly in heat, Franklin's mainly in electricity. Both had conferred upon them the very distinguished honor of being elected foreign associates of the Paris Academy of Sciences, one of the greatest distinctions that can come to a scientist. Franklin was elected in 1772, Count Rumford in 1803.

Franklin's investigations are so well known that we shall give them less attention than their importance deserves.[19] Franklin is probably more nearly worthy of being called a man of universal genius than is any other American. He was a journalist, diplomat, statesman and patriot, he was a student of electricity and several other sciences, he was a successful experimenter and also an ingenious builder of scientific hypotheses. Not before the age of forty did he become interested in electricity, and then only by chance. Peter Collinson, a London merchant and member of the Royal Society, sent to the Library Company in Philadelphia a glass tube with instructions how to use it in electrical experiments. Franklin's curiosity having been excited, he gave himself up to the study of electricity. In 1747 he wrote, "I never have before engaged in any study that so totally engaged my time as this has lately done."[20] There was formed in Philadelphia a small group of experimenters, consisting of Franklin, Ebenezer Kinnersley, Thomas Hopkinson, and Philip Sing. That year Franklin noticed the "wonderful effect of pointed bodies, both in drawing off and throwing off the electrical fire." In 1749 he made experiments which tended to show a close agreement between the "electrical fluid" and lightning. In 1752 he made his famous experiment with the kite. He suggested that buildings be protected by lightning rods. Rods proved to be no absolute protection; hence Robert Patterson of Philadelphia, Loammi Baldwin[21] of Woburn, Aaron Putnam of Charlestown, and others suggested various improvements in the method of construction.

Franklin felt the need of a theory of electricity and he advanced in 1750 what has been termed the "one-fluid" theory, according to which this electrical fluid or "electrical fire" exists as a constituent of all matter, that more than a normal amount of this fluid in a body yields a positive electrical charge, while a less than normal amount yields a

negative charge. This theory was not generally accepted by physicists. In fact, it encountered a serious rival in the "two-fluid" theory, set up by the French scientist Charles du Fay and elaborated by Robert Symmer, a member of the Royal Society of London, in 1759; this postulated the existence of two weightless fluids, called the positive and negative electricity. A positively charged body contained more of the positive fluid, a negatively charged body more of the negative fluid. From the standpoint of economy in hypotheses, Franklin's theory had the advantage, since it postulated only one fluid. Franklin, moreover, kept the notions of electricity and matter in closer union; according to him "The electrical matter consists of particles extremely subtle, since it can permeate common matter, even the densest, with such freedom and ease as not to receive any appreciable resistance." The researches of the twentieth century have driven the "two-fluid" theory out of existence and have brought Franklin's view into renewed prominence. Says Millikan, "The result of the past fifteen years has been to bring us back very close to where Franklin was in 1750, with the single difference that our modern electron theory rests upon a mass of very direct and very convincing evidence."[22]

Benjamin Franklin was in correspondence with many men of science. He and John Winthrop exchanged views on scientific subjects. In 1758 Franklin sent electrical apparatus from London to Winthrop at Harvard. At other times he forwarded scientific publications. On Nov. 15, 1764, Winthrop stated that he "had the pleasure of a visit" from Franklin the preceding summer. On May 31, 1788, Franklin wrote to James Bowdoin of Boston, "Our much regretted Friend Winthrop once made me the Compliment, that I was good at starting Game for Philosophers; let me try if I can start a little for you." And then Franklin proceeds with speculations on the possible cause of the earth's mag-

netism[23] which constitute indeed a wonderful display of what Tyndall called the "scientific imagination."

Through the influence of Benjamin Franklin in Philadelphia and John Winthrop at Harvard College, some attention to problems in physics was given by a few writers. Thus William Bryant[24] gave an account of the electrical eel or the torpedo of Surinam. David Rittenhouse, Arthur Lee, John Jones and Francis Hopkinson[25] of Philadelphia, Eli Forbes[26] of Gloucester, Loammi Baldwin of Woburn, studied the behavior of lightning rods and the freaks of strokes of lightning. Rittenhouse speculated also on the nature of magnetism and anticipated the views of Wilhelm Weber of Göttingen. Says Rittenhouse.[27] "These magnetical particles I suppose have each a north and south pole, and that they retain their polarity, however the metal may be fused or otherwise wrought. In a piece of iron which shows no signs of magnetism these magnetical particles lie irregularly, with their poles pointing in all possible directions, they therefore mutually destroy each other's effects. By giving magnetism to a piece of iron we do nothing more than arrange these particles, and when this is done it depends on the temper and situation of the iron whether that arrangement shall continue, that is, whether the piece of metal shall remain for a long time magnetical or not." The consideration of a question of fundamental theory is seen also in James Madison's experiment, whether a magnet can exert its influence in a Torricellian vacuum. He thought its action was "sensibly less," but warned the reader that he was not able to experiment with a tube of sufficient diameter for accurate determination.[28]

Nature of Light. Franklin argued against Newton's emission theory of light and in favor of the wave theory, fifty or more years earlier than did Thomas Young and Augustin Fresnel; he did this at a time when Newton's theory had met with almost universal acceptance. In 1752

Franklin wrote:[29] "I am not satisfied with the doctrine that supposes particles of matter, called light, continually driven off from the sun's surface, with a swiftness so prodigious! Must not the smallest particle conceivable have, with such a motion, a force exceeding that of a twenty-four pounder discharged from a cannon? Must not the sun diminish exceedingly by such a waste of matter? . . May not all the phenomena of light be more conveniently solved, by supposing universal space filled with a subtle elastic fluid, which, when at rest, is not visible, but whose vibrations affect that fine sense in the eye, as those of air do the grosser organs of the ear? We do not, in the case of sound, imagine that any sonorous particles are thrown off from a bell, for instance, and fly in straight lines to the ear; why must we believe that luminous particles leave the sun and proceed to the eye? . . . . May not different degrees of the vibration of the above-mentioned universal medium occasion the appearances of different colors? I think the electric fluid is always the same; yet I find that weaker and stronger sparks differ in apparent color; some white, blue, purple, red; the strongest, white; weak ones, red." It must be admitted that Franklin's argument against the emission theory and in support of the wave-theory is not conclusive. James Bowdoin, president of the American Academy of Arts and Sciences, published a paper in which he argued against Franklin and in favor of Newton's hypothesis.[30]

Heat. Count Rumford's epoch-making experiments are well known. As they were carried on abroad, we shall omit a description of them. They demonstrated that heat could not be a substance as had been held by most eighteenth century philosophers, but was due to molecular motion.

On November 16, 1770, before Rumford had begun his experiments, a physican, Hugh Williamson, read before the American Philosophical Society in Philadelphia a paper on comets containing also conjectures on the origin of heat[13]

He considers heat as a mode of motion. "Whatever produces a tremulous motion in the particles of any body, excites heat in that body, and *vice versa*. . . . Does heat therefore consist in nothing else than the rapid vibrations of the minute particles of any body?"

In a communication addressed to David Rittenhouse and dated June 20, 1788, entitled "New and curious theory of Heat and Light"[32], Benjamin Franklin uses language which is very strange, if one considers that it was written at a time when the corpuscular theory of light and the material theory of heat were at their height. Says Franklin: "Universal space, as far as we know of it, seems to be filled with a subtle fluid. whose motion or vibration is called light." He did not consider heat to be due to the motion of small particles or molecules as did Williamson but rather to be vibrations of the ether. How close Franklin was to the more modern views on radiant energy is shown by the following passage: "This fluid may possibly be the same with that which being attracted by and entering into other more solid matter, dilates the substance by separating the constituent particles and so rendering some solids fluid, and maintaining the fluidity of others; . . . as there may be a continuity or communication of this fluid through the air quite down to the earth, is it not by the vibrations given to it by the sun that light appears to us; and may it not be, that every one of the infinitely small vibrations, striking common matter with a certain force, enters its substance, is held there by attraction, and augmented by succeeding vibrations, till the matter has received as much as their force can drive into it? Is it not thus that the surface of this globe is continually heated by such repeated vibrations in the day, and cooled by the escape of the heat when those vibrations are discontinued in the night or intercepted and reflected by clouds?"

These and other passages that we might quote illustrate the truth of the remark made by John Winthrop, that Franklin possessed extraordinary ability of starting big game for the natural philosophers to pursue and run down.

A few years later we find printed in the same Transactions a paper by the aged English chemist, Joseph Priestley, who spent the sunset years of his life in America. Priestley states on February 5, 1796: " . . . light and heat are almost universally allowed to be *substances,* though no person has been able to weigh them."

But the general sentiment among chemists and physicists crystallized in favor of the materialistic theory of heat. America's noted chemist, Robert Hare of Philadelphia, in 1822, gave his reasons for rejecting the kinetic theory of Rumford and Davy.

To show the breadth of Franklin's scientific interests, we add that he suggested alterations in the construction of fire-places, made (as previously stated) a study of storms and of the Gulf Stream, invented bifocal lenses, founded the first American public hospital, suggested water-tight compartments in the building of ships, and devised (as already shown) some exceedingly involved and interesting magic squares. He discussed a problem, treated by Newton, on the form a ship should have to offer the least resistance to its motion through the water. He pointed out that mathematicians "have considered a ship as a body moving through one fluid only, the water; and to have given little attention to the circumstance of her moving through another fluid, the air."[33]

Not without interest are the introduction of the steam engine in America and the experiments antedating Robert Fulton's memorable trip on the Hudson in 1807 in the steam boat "Clermont." Benjamin Henry Latrobe of Philadelphia in 1804 reports on this subject as follows:

"Steam-engines[34] on the old construction, were introduced in America above 40 years ago. Two, I believe, were put up in New-England before the revolutionary war; and one, (which I have seen) at the copper-mine on the river Passaick, in New Jersey, known by the name of the Schuyler-mine. All the principal parts of these engines were imported from England. With the Schuyler-mine engine, Mr. Hornblower, the uncle of the younger Hornblower, who is well known as a skillful and scientific engine-builder, and whose calculations on the power of steam are extremely useful, came to America. He put up the engine, which at different times has been at work during the last thirty years, and which, notwithstanding its imperfect construction, and the faulty boring of its cylinder, effectually drained the mine.

"During the general lassitude of mechanical exertion which succeeded the American revolution, the utility of steam-engines seems to have been forgotten; but the subject afterwards started into very general notice, in a form in which it could not possibly be attended with much success. A sort of mania began to prevail, which indeed has not yet entirely subsided, for impelling boats by steam-engines.—Dr. Franklin proposed to force forward the boat by the immediate action of steam upon the water. (See his Works.) Many attempts to simplify the working of the engine, and more to employ a means of dispensing with the beam, in converting the vibratory into a rotary motion, were made. For a short time a passage-boat, rowed by a steam-engine, was established between Bordentown and Philadelphia: but it was soon laid aside. The best and most powerful steam-engine which has been employed for this purpose, excepting perhaps one constructed by Dr. Kinsey, with the performance of which I am not sufficiently acquainted, belonged to a few gentlemen of New York. It was made to act, by way of experiment, upon oars, upon paddles, and upon flutter wheels. Nothing in the success of any of these experiments appeared

to be a sufficient compensation for the expense, and the extreme inconvenience of the steam-engine in the vessel."

Submarines. Other fundamental ideas found their way into print. Thomas Jefferson, deeply interested in all lines of intellectual endeavor, contributed a "description of a mould-board of the least resistance," i. e., the mould-board of a plough.[35]

D. Bushnell[63] of Connecticut in 1787 gave the description of a submarine vessel, constructed in 1775; an assistant went into it. "I made him descend and continue at particular depths, without rising or sinking, row by the compass, approach a vessel, go under her, and fix the wood-screw . . . into her bottom."

1. Voiron, *Histoire de l'astronomie depuis* 1781 *jusqu' à* 1811, Paris, 1810, p. 57, 58.
2. J. Richer, *Observations astronomiques et physiques faites en l'isle de Cayenne,* Paris, 1679.
3. La Condamine, Narrative of Travels, in *Voyages and Travels,* by John Pinkerton, Vol. 14, London, p. 249.
4. *Philosophical Transactions,* Abridged, Vol. 8, Part 1, London, 1747, p. 238.
5. I. Todhunter, *Mathematical Theories of Attraction,* Vol. 1, London, 1873, p. 118.
6. I. Todhunter, *loc. cit.,* Vol. 1, London, 1873, p. 248.
7. *Complete Works of Benjamin Franklin,* Ed. John Bigelow, Vol. 2, 1887, p. 267, 283.
8. *Loc. cit.,* Vol. IX, 1888, p. 181-3, 201.
9. C. F. Talman, *Outlook,* Sept. 5, 1923, p. 29.
10. *Memoirs of the American Academy of Arts and Sciences,* Vol. III, Part I, Cambridge, 1809, p. 95.
11. *Loc. cit.,* Vol. II, 1786, p. 175.
12. R. Wolf, *Geschichte der Astronomie,* München, 1877, p. 697, 698.
13. *Philosophical Transactions,* Vol. 37, London, p. 55. Abridged, Vol. VI, Part II, p. 115-121.
14. *Memoirs Am. Acad. of Arts and Sciences,* Vol. 1, Boston, 1785, p. 327.
15. *The Complete Works of Benjamin Franklin,* by J. Bigelow, Vol. 2, 1887, p. 146, 253.
16. *Mexico, Its Social Evolution,* Tome I, Vol. 2, Mexico, 1900, p. 439.
17. *Gaceta de literatura de Mexico,* Dec. 22, 1789. Reprinted in *Gacetas de Mexico,* Vol. 1, Puebla, 1831, p. 423.
18. Antonio de Ulloa, *Voyage Historique de l'Amérique Méridionale,* Vol. II, 1752, chap. X, p. 66, 67.

19. A good account of Franklin as a physicist was given by George F. Barker in the *Proceedings of the Am. Philos. Society,* Vol. 32, Philadelphia, 1894, p. 104, 158. See also R. A. Millikan, *The Electron,* Chicago, 1918.

20. *Works of Benjamin Franklin,* edited by Jared Sparks, Boston, 1837, Vol. V, p. 181.

21. *Memoirs of the American Academy of Arts and Sciences,* Vol. 2, Part 2, Boston, 1793, p. 96, 99.

22. R. A. Millikan, *The Electron,* Chicago, 1918, p. 24. See also pages 12-14.

23. *The Writings of Benjamin Franklin,* edited by A. H. Smyth, Vol. IX, p. 653.

24. *Trans. Am. Phil. Soc.,* Vol. II, Philadelphia, 1786, p. 166.

25. *Trans Am. Philos. Soc.,* Vol. III, Philadelphia, 1793, p. 119, 122.

26. *Memoirs of the American Academy of Arts and Sciences,* Vol. I, Boston, 1785, p. 247, 253, 257.

27. *Trans. Am. Phil. Soc.,* Vol. 2, 1786, p. 179.

28. *Transactions of the Am. Phil. Soc.,* Vol. 4, p. 323.

29. Letter to Calwallader Colden, April 23, 1752, in John Bigelow's *Complete Works of Benjamin Franklin,* Vol. 2, New York and London, 1887, p. 254, 255.

30. See Bowdoin's address in *Memoirs of the American Academy of Arts and Sciences,* Vol I, Boston, 1785, p 187. Bowdoin College is named in his honor.

31. *Transactions Am. Philos. Society,* vol. I, p. 138. Philadelphia, 1789.

32. *Transactions Am. Philos. Society,* vol. III, p. 5, 1793.

33. *Transactions Am. Philosophical Soc.,* Vol. II, Philadelphia, 1786, p. 294.

34. First Report of Benjamin Henry Latrobe, to the American Philosophical Society, held at Philadelphia; in answer to the inquiry of the society of Rotterdam, "Whether any and what improvements have been made in the construction of Steam-Engines in America?" in *Transactions of the American Philosophical Society,* Vol. VI, Part I, Philadelphia, 1804, p. 89-90.

35. *Trans. Am. Philos. Society,* Vol. 4, Philadelphia, 1799, p. 309.

36. *Loc. cit.,* Vol. 4, p. 313.

CHAPTER XI

SOCIETIES, ACADEMIES AND JOURNALS

That leaders of thought of the eighteenth century in Philadelphia, Boston and New Haven had shown interest in scientific pursuits is evident from the founding of academies or societies in these cities. At irregular intervals scientific volumes were published. The "American Philosophical Society" was founded in Philadelphia in 1743 through the influence of Benjamin Franklin, but it soon languished. In 1766 a new organization was attempted under the name of "American Society." Meanwhile a few surviving members of the old society of 1743 reorganized, secured as members some influential and wealthy colonists, and initiated plans for the observation of the transit of Venus in 1769. At this time negotiations for the union of the two societies were started, which occupied nearly a year and culminated in the absorption of the American Society by the American Philosophical Society. Among those most active in bringing about this union were Charles Thompson, John Dickinson, John Lukens, Thomas Mifflin and David Rittenhouse, of the American Society, and Dr. William Smith of the other. With the union of the two societies in January 1769 came the appointment of a committee to observe the transit of Venus on June 3 of that year. The American Philosophical Society published transactions during the years 1771-1809; then there followed an interruption until 1818. It should be remarked F. R. Hassler was admitted to membership upon his arrival from Switzerland in 1805 and that members of the Society were influential in starting the United States Geodetic Survey. The "American Academy of Arts and Sciences" was founded in Boston in 1780. While the society

in Philadelphia has been modeled after the Royal Society of London, the one in Boston took the Paris Academy as its ideal. The Philadelphia organization dates its origin to colonial times; the one in Boston to the later period which brought hostility to England. And so it came that the Massachusetts association was not a "society" but an "academy;" its publications were not "transactions," but "memoirs." These Memoirs were published during 1785-1821, when an interruption took place until 1833. At New Haven the "Connecticut Academy of Arts and Sciences" was organized in 1799, but nothing was published until 1810-16, when Vol. 1 of its *Memoirs* appeared; from 1817 to 1910 the Memoirs were suspended, but the Academy has published Transactions since 1866. Abroad, learned societies and academies were started much earlier. Some date back as early as the sixteenth and seventeenth centuries. The Royal Society of London was definitely chartered in 1662, the Académie des Sciences in Paris in 1666. In the eighteenth century such societies existed in Berlin, Petrograd, Stockholm, Göttingen, Munich, Brussels, Prague, Turin, Rome, Dublin and several other intellectual centers.[1]

Scientific Journals. There were no scientific journals in America, of non-ephemeral or permanent existence until the foundation at New Haven of Silliman's *American Journal of Science,* in 1818; but there was a considerable number of scientific periodicals of short lives, which contributed toward the creation of a general interest in science.

In New Spain (Mexico), the honor of having started scientific periodicals in the eighteenth century belongs to José Antonio Alzate and Ignacio Bartolache. There was a rivalry between these two scientists which was not always friendly. Bartolache was more firmly grounded in mathematics and astronomy than Alzate, but the latter engaged in a wider range of scientific study. In the history of scientific journals Bartolache appears as the editor of the

Mercurio Volante which he started in Mexico City in 1772. It contained notices of various matters of interest in the physical sciences and medicine, but it enjoyed only an ephemeral existence. Bartolache was a pupil of Joaquin Velázquez de León and assumed the instruction of mathematics at the University of Mexico when Velázquez was sent to California to observe the transit of Venus in 1769. After his return to Mexico Bartolache assisted him, as we have seen, in his astronomical observations. Bartolache published in 1769 at Mexico his *Lecciones matematicas.* We have seen only the first part of this, a meagre syllabus which did not impress us. In a scholium the importance of mathematical rigor in intellectual endeavor is emphasized, reference being made to Malebranche and Descartes. Bartolache was noted for his wide attainments and "his philosophic independence that led him to sustain, in a public act, the necessity of reforming the ideas reigning in science and of putting a stop to peripateticism, thereby bringing upon himself a bloody persecution."[2]

Alzate, in 1768, began the publication of the *Diario literario de Mexico* which was soon suppressed, but it reappeared under a new title, to be again suppressed after eleven numbers had been issued, only to spring into existence a third time in 1787 under another name and going through fourteen issues. In 1788 the famous monthly, *Gaceta de Literatura de México* was started and it continued, though with some irregularity, as a literary and scientific review until 1799, the year of Alzate's death. The leading articles in the *Gaceta* and the *Diario* were published in four volumes at Puebla in 1831. In the *Diario* of April 8, 1768, occurs a protest against the fake forecasts of fevers and other disasters contained in almanacs. For the enlightenment of the reader the translation of an article on astrology[3] written by a French scientist is inserted. The journals contain information on the geography and meteorology of

Mexico, and notices of scientific progress in Europe. Theories about earthquakes, Lavoisier's system of chemistry, and Franklin's experiments on electricity, received marked attention.

Alzate represented, more than any one else of his time, *experimental* science in Mexico. We have seen that he took astronomical and meteorological observations; he made experiments on electricity, "exposing his life many a time and destroying his health," and also worked in the field of natural history[4] and of antiquarian research. He published many scientific tracts and articles, some of which were favorably noticed in France. He was a correspondent of the Royal Academy of Sciences at Paris. The deep esteem in which he has been held by subsequent generations of his countrymen is evident from the fact that the scientific society organized in Mexico in 1885, bears the name "Sociedad Cientifica 'Antonio Alzate.'"[5]

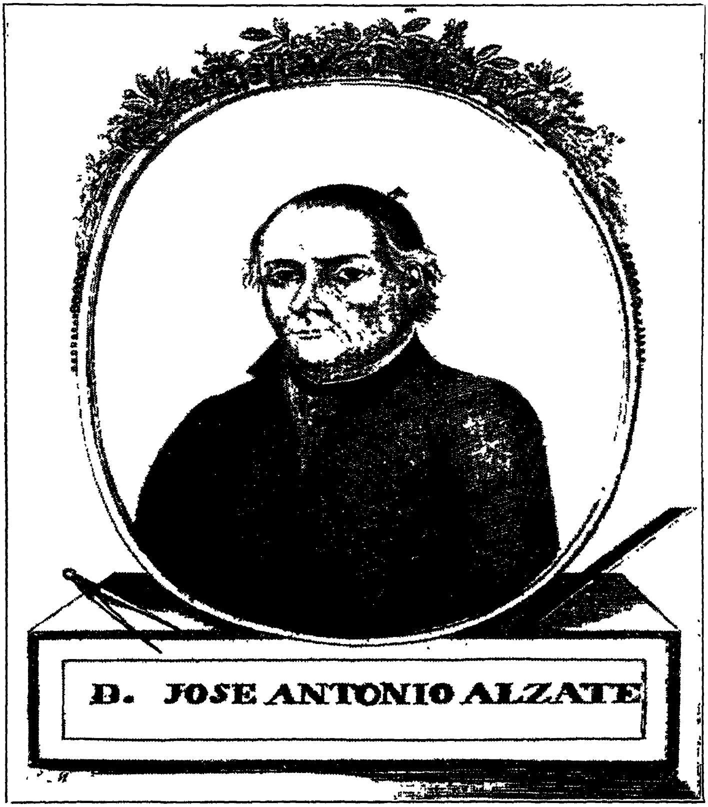

Fig. 32. José Antonio Alzate y Ramirez.

CONCLUSION

This rapid survey gives indication of early scientific activity in America worthy of systematic record. That much of it was the product of European talent is not surprising. That some of it represented the achievement of men born and educated in America is a source of satisfaction. The quality of work was mainly observational, consisting of the gathering of data on eclipses, transits, parallaxes, comets, electricity, meteorology, altitudes of celestial bodies, pendulum experiments, geodetic base measurement and atmospheric refraction. The applications of these data to scientific theory were made in the scientific centers of Europe where the data from different parts of the world could be gathered. Except for Sigüenza's general map of Mexico, the more important of the early maps were prepared in Europe by C. Delisle, G. B. Riccioli and others. The study of the shape and size of the earth and the preparation of tables of correction for astronomical refraction were made by astronomers in the old world. Nevertheless, even before the nineteenth century, America, though merely a distant outpost, was an integral part of the field of operations of the great army of scientific workers. The frontier of civilization in America played a real part in the advancement of the frontier of human knowledge.

1. For fuller information see Scudder's *Catalogue of Scientific Serials, 1633-1876;* Cambridge, 1876; H. C. Bolton's *Catalogue of Scientific and Technical Periodicals, 1665-1882,* 1885..
2. *Mexico, Its Social Evolution,* Tome I, Vol. 2, Mexico, 1900, p. 439.
3. The article "astrologie" in Saverien's *Dictionnaire universel de mathématiques et de physiques,* Paris, 1753.
4. *Mexico, Its Social Evolution,* Tome I, Vol. 2, Mexico, 1900, p. 439.
5. We have elsewhere (p. 26, 126) called attention to scientific publications which existed for short periods in Colombia and in the United States.

INDEX